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NOVEL FORAGE LEGUMES FOR SUSTAINABLE SUMMER PASTURE MIXTURES IN SASKATCHEWAN

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ABSTRACT

Two experiments were conducted (2016 and 2017) to determine the potential of perennial binary legume-grass mixtures. Experiment 1 evaluated effect of July and September harvest dates on stockpiled forage dry matter yield, quality and botanical composition of legume and grass species at AAFC SCRDC-Swift Current (Brown soil site) and AAFC Saskatoon (Dark Brown soil site), Saskatchewan. Experiment 2 evaluated forage dry matter yield (DMY), quality, grazing animal preference and performance, and cost-benefits analysis of binary legume-grass mixtures at AAFC SCRDC-Swift Current (Brown soil site) and WBDC-Lanigan (Thin Black soil zone) Saskatchewan. Experiment 1 forage varieties included AC Yellowhead alfalfa (ALF), AC Mountainview sainfoin (MSF), Nova sainfoin (NSF), Shoshone sainfoin (SSF), Delaney sainfoin (DSF), AC Veldt cicer milkvetch (CMV), Great Plains Ecovar Canadian milkvetch (GCM), AC Lamour purple prairie clover (PPC) and Antelope white prairie clover (WPC) in binary mixtures with either Tom Russian wildrye (RWR), AC Success hybrid bromegrass (HBG) or Admiral meadow bromegrass (MBG) in a split-plot arrangement of a randomized complete block design (RCBD). Forage DMY of tame binary mixtures were greater ($P = 0.01$) at AAFC Saskatoon than AAFC SCRDC site. Forage DMY differed ($P = 0.01$) among tame binary mixtures ranging from 1,828 (NSF-RWR) to 4,826 kg ha^{-1} (ALF-HBG) and 4,511 (NSF-RWR) to 10,113 kg ha^{-1} (CMV-HBG) mixtures at AAFC SCRDC and AAFC Saskatoon, respectively. Forage DMY also differed ($P = 0.01$) among native binary mixtures ranging from 884 (WPC-RWR) to 3,582 kg ha^{-1} (PPC-HBG) mixtures at AAFC SCRDC site. Year of harvesting forages at both sites were greater ($P < 0.05$) in 2016 than 2017. Dry matter yield of mixtures harvested in September were 15 to 20% lower ($P = 0.01$) than July harvest yields in yr 2 at both study sites. Nutritive value of binary mixtures was 26 to 46% greater ($P < 0.05$) at AAFC Saskatoon

compared to AAFC SCRDC-Swift Current site because of precipitation. Among the binary mixtures, CMV-RWR and GCM-RWR mixtures (native binary mixture) ranked the highest in nutritive value at both sites. RWR was more compatible with forage legumes ($\geq$ 50 % legumes) compared to MBG and HBG in mixtures with legumes. Most native binary mixtures may not be recommended as fall stockpiled forage due to low CP level not meeting CP requirement of grazing animals and yielding less than 2,000 kilogram per hectare. Based on the 2 yr study, it is not recommended to seed either HBG or MBG in a binary mixtures with a legume in a mixed-row seeding pattern. Experiment 2 evaluated alfalfa (ALF) (*Medicago falcata* L.; cv. AC Yellowhead) and sainfoin (SF) (*Onobrychis viciifolia* Scop; cv. AC Mountainview) in binary mixtures with either Russian wildrye (RWR) (*Psathyrostachys junceus* [Fisch.]; cv. Tom) or hybrid bromegrass (HBG) (*B. riparius* Rehm × *B. inermis* Leyss; cv. AC Success) in a randomized complete block design at WBDC-Lanigan and AAFC SCRDC-Swift Current sites. Yearling steers (yr 1, n = 40, BW = 404 kg $\pm$ 18 kg; yr 2, n = 48, BW = 400 kg $\pm$ 16 kg) at AAFC SCRDC, and heifers (yr 1, n = 64, 364 kg $\pm$ 51) and steers (yr 2, n = 48, BW = 338 kg $\pm$ 23 kg) at WBDC were randomly allocated to 1 of 4 replicated (n=4) pasture types, (i) ALF-RWR; (ii) ALF-HBG; (iii) SF-RWR; and (iv) SF-HBG mixtures. Forage DMY were greater (P = 0.01) for HBG + legume mixtures at WBDC than at AAFC SCRDC and similar (P > 0.05) for RWR+ legumes mixtures at both sites. Forage DMY differed (P = 0.01) among binary mixtures ranging from 3,638 (SF-RWR) to 5,901 kg ha^{-1} (ALF-HBG) at WBDC site. In contrast, DMY was similar (P = 0.84) among binary mixtures ranging from 3,931 (ALF-HBG) to 4,140 kg ha^{-1} (ALF-RWR) at AAFC SCRDC site. Hand plucked samples had greater (P < 0.05) nutritive value in yr 2 at WBDC compared to clipped forage samples. However, at AAFC SCRDC, nutritive values from hand plucked samples were similar (P > 0.05) to clipped samples. Estimated forage dry matter intake (kg d^{-1}) and forage utilization (%) were similar ($P > 0.05$) among binary mixtures at both sites. Average daily gain (ADG) was similar ($P = 0.32$) among binary mixtures at AAFC SCRDC. However at WBDC, ADG differed ($P = 0.02$) among binary mixtures in yr 2 ranging from 0.64 to 1.1 kg d^{-1} for ALF-HBG and SF-RWR mixtures, respectively. Animal grazing days (AGD) ($P = 0.26$) and total beef production (TBP) ($P = 0.59$) at WBDC were similar in both yrs, for all pasture mixtures ranging from 78 to 116 AU ha^{-1} AGD and 58 to 78 kg ha^{-1} TBP, respectively. However, at AAFC SCRDC in yr 2, AGD and TBP differed ($P = 0.01$) with steers grazing ALF-HBG mixtures having greater AGD (121 vs 74 AU ha^{-1}) and TBP (120 vs 67 kg ha^{-1}) compared to steers grazing the SF-RWR (74 AU ha^{-1}) pasture. Despite the late summer and fall grazing, stocker performance was improved at both sites.

Costs to seed perennial mixtures differed ($P = 0.01$) in both yrs and at both sites ranging from \$ 58.78 (ALF-RWR) to 82.06 (SF-HBG) per ha at AAFC SCRDC and \$ 29.00 to 49.09 and 75.95 to 96.03 per ha in yr 1 and yr 2 at WBDC, respectively. Value of gain (\$ ha^{-1}) ($P = 0.66$, yr 1; $P = 0.27$, yr 2) and net returns ($P = 0.42$, yr 1; $P = 0.47$, yr 2) were similar among mixtures at WBDC site. However, value of gain and net returns differed ($P = 0.01$ vs. $P = 0.02$) among mixtures in yr 2 at AAFC SCRDC site. These results suggest that beef producers can adopt placing a value on forages for higher profit compared to compensation rates for custom grazing and animal grazing days. Despite differences in agro-climatic condition, all binary mixtures were profitable for late summer and fall grazing in southwest and central Saskatchewan.

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LIST OF ABBREVIATIONS

AAFC	Agriculture and Agri-Food Canada
ADF	Acid detergent fibre
ADL	Acid detergent lignin
ALF	AC Yellowhead alfalfa
Ca	Calcium
GCM	Great Plains Ecovar Canadian milkvetch
CMV	AC Veldt cicer milkvetch
CP	Crude protein
DSF	Delaney sainfoin
DMI	Dry matter intake
DMY	Dry matter yield
HBG	AC Success hybrid bromegrass
IVOMD	*In vitro* organic matter digestibility
K	Potassium
MBG	AC Admiral meadow bromegrass
MSF	AC Mountainview sainfoin
N	Nitrogen
NASEM	National Academics of Sciences, Engineering and Medicine
NDF	Neutral detergent fibre
NSF	Nova sainfoin
OM	Organic matter
P	Phosphorus
PPC	AC Lamour purple prairie clover
RWR	Tom Russian wildrye
SCRDC	Swift Current Research Development Center
SSF	Shoshone sainfoin
SK	Saskatchewan
SOM	Soil organic matter

TDN	Total digestible nutrient
WBDC	Western Beef Development Center
WPC	AC Antelope White prairie clover

1 Introduction

Pasture productivity is key to profitable beef production in western Canada. It is well documented that two common recommendations in the Canadian Prairie Provinces for grass pasture improvement include fertilization at soil-test recommended rates or inclusion of a legume species such as alfalfa at the time of seeding (Lardner et al., 2000; Kopp et al., 2004). Applying commercial nitrogen fertilizer to grass-based pasture can only be cost-effective strategies in years of adequate precipitation (Kopp et al., 2003). In contrast, addition of legumes such as alfalfa to the pasture mix at establishment is likely to be the most cost-effective strategy as it generally increases pasture productivity and calf gains without additional cost (Kopp et al., 2003; 2004). There are few data available to assess the impact of the latter recommendation for pastures seeded to improved grass species such as hybrid bromegrass and Russian wildrye on the grazing preference, performance of beef cattle and economics in the Brown and Black soil zones of the Canadian prairies.

Grazing animal productivity is dependent on forage quality. Forage availability and quality in late summer and fall months are important for maintaining beef cattle weight. Forage legumes compensate for the ‘summer slump’ of cool-season grasses during this period and can improve the seasonal distribution of pasture forage, thereby increasing the number of livestock that can be supported (Sleugh et al., 2000; Cox, 2013). Forage legumes such as alfalfa (*Medicago sativa* L.) improves pasture nutrition later in the growing season when many of the perennial grasses experience a quality decline (Sanderson and Wedin, 1989; Hendrickson and Berdahl, 2003). Alfalfa can improve carrying capacity and maximize beef production as a monoculture or dominant species in forage mixtures (Popp et al., 2000). However, alfalfa causes bloat responsible for mortalities in grazing cattle (Popp et al., 2000; Cox, 2013). It is therefore recommended that alfalfa be grown with grass species to offset the potential for bloat.

Sainfoin (*Onobrychis viciifolia* Scop.), has shown to yield between 15 to 25% less than alfalfa in the Canadian prairies (Goplen et al., 1991). Lambs grazing sainfoin monoculture resulted in a higher live weight gain (LWG), which was attributed to a 14% higher intake and 20% greater biomass utilization compared to alfalfa (Karnezos et al., 1994). Sainfoin, purple prairie clover (*Dalea purpurea* Vent.), and white prairie clover (*D. candida* Michx. Ex Willd) are forage legumes with moderate to high concentration of condensed tannins. Canadian milkvetch (*Astragalus canadensis* L.) is a non-bloating legume without tannins in foliage but containing seed coat at the seed mature stage (Li et al., 2014). These legumes are non-bloating (Li et al., 1996; Berard et al., 2011), allow protection of plant protein from microbial degradation (Waghorn et al., 1987; Aerts et al., 1999) and have shown improved live weight gain and milk yield (Wang et al., 1996; Berard et al., 2011).

Hybrid brome grass (*Bromus riparius* Rehm x *Bromus inermis* Leyss) was developed in Canada by hybridizing of smooth bromegrass and meadow bromegrass to offer increased flexibility in forage management systems (Ferdinandez and Coulman, 2001). It is a dual-purpose forage for both hay and pasture systems, producing a high quality, high volume of first cut hay crop (like smooth bromegrass) followed by good regrowth for grazing and stockpiling (like meadow bromegrass). The yield and quality of this grass species has shown potential for use in beef production system (Ferdinandez and Coulman, 2001) in the Canadian prairies.

Russian wildrye (*Psathyrostachys junceus* [Fisch.] Nevski) is an excellent species palatable to all classes of livestock and wildlife (Ogle et al., 2012a) and of adequate nutritive quality for matured stock on winter maintenance rations (Sedivec et al., 2007). Russian wildrye is very tolerant of grazing and regrows quickly after grazing if soil moisture is available (Ogle et al., 2012a). It is high in protein and retains higher protein content than most grasses after maturity (Ogle et al., 2012a).

Pasture productivity and longevity are also essential for an efficient and profitable operation. With increasing land values, rapid urbanization and high cost ($ 0.48 per cow and calf per day) plus trucking and travel cost to graze Government-owned community pastures (Saskatchewan Agriculture and Food, 2000), producers need to find ways to increase the productivity of forages on their current land base. Additionally, as the grazing season progresses forage quality declines and animal gains are diminished. By incorporating new forage legumes in mixture with grasses there is improved yield and quality which maintains animal gains in summer and fall months. To make recommendations for beef producers it is prudent to evaluate the combined effects of various legume mixtures with grass species for their profit potential when used for beef animal grazing in the Canadian Prairie Provinces.

The null hypotheses are that; (i) forage productivity, botanical composition, quality and grazing animal's preference and performance will be similar between legume-grass mixtures managed as summer pastures in both the Brown soil and Thin Black soil zones of Saskatchewan, (ii) the calculated cost-benefits analysis of establishing novel legumes in mixed stands with grass species will be similar in both Brown and Thin Black soil zones in Saskatchewan, and (iii) forage productivity, botanical composition and quality of binary legume-grass pasture mixtures on July and September harvest dates will be similar in both the Brown and Dark Brown soil zones in Saskatchewan.

The objectives of the study are to evaluate; (i) forage dry matter (DM) yield and quality of AC Yellowhead alfalfa (ALF) and AC Mountainview sainfoin (SF) in mixtures with either

Tom Russian wildrye (RWR) or AC Success hybrid bromegrass (HBG), (ii) the grazing animals preferences and performance managed on these grass-legume pastures in both the Brown (Swift Current) and Thin Black (Lanigan) soil zones of Saskatchewan, (iii) the calculated cost-benefits for forage-legume pastures where cost is based on stand establishment for the SF and ALF mixed stands and the benefit is revenues from beef cattle weight gain while grazing forage-legume pastures, and (iv) the effects of July and September harvest dates on forage DM yield, botanical composition and quality in the Dark Brown (Saskatoon) and Brown soil zone (Swift Current) in Saskatchewan.

1.1 References

Aerts, R.J., Barry, T.N. and McNabb, W.C. 1999. Polyphenols and agriculture: Beneficial effects of proanthocyanidins in forages. Agric. Ecosyst. Environ. 75:1–12.

Berard, N.C., Wang, Y., Wittenberg, K.M., Krause, D.O., Coulman, B.E., McAllister, T.A. and Ominski, K.H. 2011. Condensed tannin concentrations found in vegetative and mature forage legumes grown in western Canada. Can. J. Plant Sci. 91:669–675. http://doi.org/10.4141/cjps10153

Cox, S.R. 2013. Forage yield and quality of binary grass-legume mixtures of tall fescue, orchardgrass, meadow brome, alfalfa, birdsfoot trefoil, and cicer milkvetch. MSc Thesis. Utah State University, Logan, Utah.

Ferdinandez, Y.S.N. and Coulman, B.E. 2001. Nutritive values of smooth bromegrass, meadow bromegrass, and meadow x smooth bromegrass hybrids for different plant parts and growth stages. Crop Sci. 41(2): 473–478. http://doi.org/10.2135/cropsci2001.412473x

Goplen, B.P., Richards, K.W. and Moyer, J.R. 1991. Sainfoin for western Canada. Agriculture Canada Publi. 1470/E , Ottawa, Ont.

Hendrickson, J.R. and Berdahl, J.D. 2003. Survival of 16 alfalfa populations, space planted into a grassland. J. Range. Manage. 56:260–265.

Karnezos, T.P., Matches, A.G. and Brown, C.P. 1994. Spring lamb production on alfalfa, sainfoin, and wheatgrass pastures. Agron. J. 86: 497–502.

Kopp, J.C., McCaughey, W.P. and Wittenberg, K.M. 2003. Yield, quality and cost effectiveness of using fertilizer and/or alfalfa to improve meadow bromegrass pastures. Can. J. Anim. Sci. 83: 291–298.

Kopp, J.C., Wittenberg, K.M. and McCaughey, W.P. 2004. Management strategies to improve cow-calf productivity on meadow bromegrass pastures. Can. J. Anim. Sci. 84: 529–535.

Lardner, H.A , Wright, S.B.M., Cohen, R.D.H., Curry, P and MacFarlane, L. 2000. The effect of rejuvenation of Aspen Parkland Ecoregion grass-legume pastures on dry matter yield and forage quality. Can. J. Plant Sci. 80: 781–791.

Li, Y., Iwaasa, A.D., Wang, Y., Jin, L., Han, G. and Zhao, M. 2014. Condensed tannins concentration of selected prairie legume forages as affected by phenological stages during two consecutive growth seasons in western Canada. Can. J. Plant Sci. 94(5): 817–826. http://doi.org/10.4141/cjps2013-234

Li, Y.G., Tanner, G. and Larkin, P. 1996. The DMACA-HCl protocol and the threshold proanthocyanidin content for bloat safety in forage legumes. J. Sci. Food Agric.70: 89–101

Ogle, D., St. John, L., Cornwell, J., Holzworth, L., Majerus, M., Tober D., Jensen, K., Sanders, K.E. (rev) St. John. 2012a. Plant Guide for Russian Wildrye *(Psathyrostachys junceus).* USDA-Natural Resources Conservation Service, Aberdeen Plant Materials.

Popp, J.D., McCaughey, W.P. Cohen, R.D.H. McAllister, T.A. and Majak, W. 2000. Enhancing pasture productivity with alfalfa: A review. Can. J. Plant Sci. 80: 513–519.

Sanderson, M.A. and Wedin, W.F. 1989. Phenological stage and herbage quality relationships in temperate grasses and legumes. Agron. J. 81: 864–869.

Saskatchewan Agriculture and Food. 2000. Saskatchewan pastures program. [Online] Available: http://www.agr.gov.sk.ca/ DOCS/CR.../pasturefees.asp [21 August 2000].

Sedivec, K., Tober, D., Duckwitz, W., Dewald, D., Printz, J. 2007. Grasses for the Northern Plains. Volume 1 Cool Season. North Dakota State University Extension, Fargo, ND

Sleugh, B., Moore, K.J., George, J.R. and Brummer, E.C. 2000. Binary legume–grass mixtures improve forage yield, quality, and seasonal distribution. Agron. J. 92: 24–29.

Waghorn, G.C., John, A. Jones, W.T. and Shelton, I.D. 1987. Nutritive value of *Lotus corniculatus* L. containing low and medium concentrations for sheep. Proc. N.Z. Soc. Anim. Prod. 47: 25–30.

Wang, Y., Douglas, S.G.B., Waghorn, G.C., Barry, T.N. and Foote, A.G. 1996. Effect of condensed tannins in Lotus corniculatus upon lactation performance in ewes. J. Agric. Sci. 126: 353–362.

2 Literature Review

2.1 Forage Management

In Canada, forage crops are grown on over 36 million ha of which 72% is native range (26 million ha), 17% is tame forage crops (6 million ha) and 11% is cultivated pasture (4 million ha) (McCartney and Horton, 1997). Forages are a major contributor to the Canadian agricultural sector in contrast to some other crops like wheat or canola. In 2011, wheat growers in Canada realized net farm income of $ 5.2 billion, canola producers $ 7.3 billion and forage producers $ 5.1 billion (Statistics Canada, 2012). This therefore makes forages the third largest crop in Canada in terms of value generated at the farm level.

Forages are all edible parts of plants, other than separated grain, that can be consumed by grazing animals or mechanically harvested for feeding (Vallentine, 2001; Barnes et al., 2003). In addition, the Saskatchewan Forage Council (2011), also defined forages as that part of the vegetation that is available and acceptable for animal consumption, whether considered for grazing or conserved through mechanical harvest.

The primary use of forages is feed for livestock (cattle, sheep and horses) in Canada and conventional beef cattle production systems in North America which accounts for approximately 80% of the total forage production (Agriculture and Agri-Food Canada, 2001; Guyader et al., 2016). Therefore, forages are the backbone of sustainable ruminant livestock production in western Canada. The beef and dairy industries are the second and third ranking primary agriculture sectors after the grain sector (McCartney and Horton, 1997; Sottie, 2014). It is well documented that 67% of the feed protein in Canada comes from hay, grazing of forages and fodder corn production (McQueen and Buchanan-Smith, 1993).

2.1.1 Forage Legumes

A hallmark trait of legumes is their ability to develop root nodules and to fix nitrogen in symbiosis with compatible *Rhizobia* species. This fixed nitrogen (N) is cycled into the soil N pool through sloughing of roots and nodules, root exudation and decomposition of aboveground biomass (Mortenson et al., 2005). Legumes, in addition to meeting their own N needs, can transfer a large proportion of total N fixed to neighbouring grasses, through decomposition of secondary roots that are not thickened and legume nodules (Dubach and Russelle, 1994).

Forage legumes are also increasingly believed to be an important component of environmentally sustainable grassland ecosystems. Forage legumes are persistent under grazing and have shown to have beneficial effects on soil structure, aided by their association with mycorrhizal fungi (Frame, 2005). Other benefits of legumes include lower quantities of harmful emissions to the environment (greenhouse gases and nitrate), lower production costs, higher productivity, increased protein self-sufficiency and adaptation options to rising atmospheric CO_2 concentrations and climate change (Luscher et al., 2014).

Voluntary intake of forage legume is 10 to 15% greater than that of grasses of similar digestibility, whether fed as silage, hay or as fresh herbage (Luscher et al., 2014). This difference can be attributed to lower resistance of legumes to chewing, a faster rate of digestion and a faster rate of particle breakdown and clearance from the rumen (Waghorn et al., 1989; Luscher et al., 2014), which in turn reduces rumen fill.

It is well documented that addition of forage legumes to the grazing ruminant's diet can improve live weight gain in small ruminants (Fraser et al., 2004), and cattle (Yarrow and Penning, 2001). Lambs finished on monocultures of red clover (*Trifolium pratense* L.) or white clover (*Trifolium repens* L.) had 45 to 65% greater daily gains than those grazing perennial ryegrass (*Lolium perenne* L.) and achieved optimal market weight in fewer days (Fraser et al., 2004).

2.1.2 Carbohydrates Reserves in Forages

Plants produce energy through the process of photosynthesis for plant growth and development, maintenance and production of polysaccharides. These polysaccharides form reserves of carbohydrate called total available carbohydrates (TAC) or total non-structural carbohydrates (TNC). Ward (2009) defined plant energy reserves as "…those carbohydrates and nitrogen compounds elaborated, stored and utilized by the plant itself as food for maintenance and for the development of future shoot and root growth." From this labile pool, the plant can draw material to offset both major and minor fluctuations in the levels of simple sugars (Walton, 1983), needed for maintenance, respiration, initial growth and other needs. These energy reserves play an important role in regrowth following defoliation, over-winter survival and initiation of spring growth in forage crops (Walton, 1983). However, growth and seed production have priority over storage for carbohydrate use (Waller et al., 1985). The ability of forages to respond to these factors will ultimately affect the resilience, persistence and productivity of the plant.

2.1.3 Leaf Area Development

The leaf area of plants also plays key role in recovery from defoliation especially when carbon buffer is limited (Caldwell, 1984). This depends on the quantity of the remaining foliage and its photosynthetic capacity; also important is the rate of development of new foliage and the photosynthetic capacity of the new leaves (Caldwell, 1984).

Furthermore, moderate or low utilization of forages by grazing animals during the growing season allows enough leaf area to remain to provide carbohydrates for regrowth rather than prolonged dependence upon stored total available carbohydrates (Waller et al., 1985). Adequate leaf area remaining after defoliation for light interception and photosynthesis is important in promoting regrowth, and the leaf area index (LAI) is commonly used to determine remaining leaf area.

Studies by Parsons and Johnson (1986) showed that the rates of photosynthesis and gross biomass yield are close to maximum on swards maintained at moderate leaf area index. However, the scientists concluded that this requires an adequate and substantial proportion of the leaves produced to remain in the sward to contribute to photosynthesis. In addition, excess levels of standing biomass in dense swards inevitably gives rise to shading, reduced photosynthetic efficiency, and a high rate of foliage loss due to senescence and death.

2.1.4 Effects of Defoliation, Treading and Excretion on Regrowth

The effects of defoliation on the regrowth of forages are variable depending upon the timing, severity and frequency of defoliation (Vallentine, 2001). In alfalfa, the apical meristem is the source of new leaves and is elevated by stem elongation. When a plant is defoliated and the apical meristem removed or damaged, stem elongation and leaf expansion stops at that axis (Ward, 2009). Any subsequent regrowth-leaf replacement and tillering must arise from dormant basal meristems, which may be a slow process. In contrast, a defoliated plant prior to stem elongation, has the apical meristems remained and growth is not initiated from dormant basal buds (Vallentine, 2001). Richards et al. (1987), concluded that within a few hours to at maximum of 2 d following intensive defoliation, root growth and root respiratory activity are significantly depressed through lack of readily mobilized TAC, this being quickly utilized by continuing plant respiration and growth processes following defoliation. High TAC will not prolong growth for long if meristematic activity is not high (Richards et al., 1987).

Another activity of grazing animals that can cause changes in the sward and regrowth is treading. The hoof action of grazing animals can cause direct damage to leaves, stems, roots, growing points and surface roots. According to Bates (1993), herbage yields can be reduced by animal treading, with progressively larger reductions as stocking rate and soil moisture increase. Cattle are more likely to do more damage than sheep and goats because of their greater body weight. Damage is always likely to be less on short, dense sward than tall, open swards. Also, perennial ryegrass is less susceptible to treading damage than other grasses and legumes (Hodgson, 1990). Some studies have also shown that there can be a decrease in tiller numbers immediately after treading; however, new tillers are produced as replacements (Bates, 1993). For example, studies by Quinn and Hervey (1970), showed that trampling damages by cattle on sandhills range in northeastern Colorado varied from about 1% (22 kg ha^{-1}) under light grazing, to 2% (41 kg ha^{-1}) under moderate grazing, to 5% (67 kg ha^{-1}) under heavy stocking. This damage reduces tiller density and leaf area of plant thereby slowing growth.

Grazing animals not only affect pasture growth by defoliation and treading, but also through the deposition of urine and feces. Pasture growth can be directly or indirectly effected by the nutrients that are deposited via the animal. The N in urine directly affects pasture production by stimulating grass growth (Hodgson, 1990). However, the presence of dung and urine in a pasture can lead to the avoidance of these areas fouled by grazing animals thereby the biomass senescing and being less palatable.

2.2 Soil-Climatic Zones in Saskatchewan

Soil distribution in the prairie regions of Canada is closely related to differences in climatic and natural vegetation (Fuller, 2010). The regional variations across the prairies have resulted in the formation of soil zones which reflect the effects of precipitation, temperature and dominant vegetation type on soil-forming processes and hence on soil properties and types (Fuller, 2010; Rehemuti, 2014).

Based on the Canadian System of Soil Classification, most soils in the prairies ecosystem belong to the Chernozemic soils (Fuller, 2010), and are known as the Brown, Dark Brown, Black and Dark Gray soil zones. The soil organic matter (SOM) content of the soil reflects the colour of the soil zone; with the greater the organic matter, the darker the surface colour.

The Brown Soil zone occurs primarily in the semi-arid Mixed Grassland Ecoregion and covers approximately 6.3 million hectares in southwest Saskatchewan, of which 69% are cultivated (Agriculture and Agri-Food Canada, 2000). This soil zone has a mean annual precipitation of 358 mm (Jefferson et al., 1994). In this region, the relatively warm temperature, low soil moisture and soil organic matter content of 2.5 to 3.5% (Soils of Saskatchewan; http:www.soilsofsask.ca) limit crop growth, and short-grass species for livestock production (Agriculture and Agri-Food Canada, 2000; Rehemuti, 2014). Forage crops choices are limited, as the most dominant vegetation is presently native rangelands (Aasen and Bjorge, 2009). Some commonly used tame forages include Russian wildrye, Altai wildrye, crested wheatgrass, alfalfa, and smooth bromegrass.

The Dark Brown soil zone lies north and east of the Brown soil zone. It is associated with the Moist Mixed Grassland Ecoregion and covers 7.28 million hectares of which approximately 82% of the soil is under cultivation (Rehemuti, 2014). This soil zone is considered to be the most intensively farmed area in Saskatchewan (Agriculture and Agri-Food Canada, 2000). The Dark Brown zone is characterized by cooler and moister conditions with relatively high levels of organic matter (typically 3.5 to 4.5% in cultivated soils) at the surface than the Brown soil zone (Soils of Saskatchewan; http:www.soilsofsask.ca). This soil zone has a mean annual precipitation of 375 mm (1981-2010) according to Environment Canada's Climate Data Online (www.climate.weatheroffice.ec.gc.ca). Smooth bromegrass, meadow bromegrass, intermediate wheatgrass and crested wheatgrass are grown in this region.

The Black soil zone developed in the Aspen Parkland Ecoregion and covers 7.52 million hectares in which about 73% is being cultivated for crop production (Agriculture and Agri-Food Canada, 2000). The Black soil zone is located to the north and east of the Dark Brown soil area and has a mean annual precipitation data of 398 mm (1985-2006) according to Environment Canada's Climate Data Online (www.climate.weatheroffice.ec.gc.ca). Although, the growing season is shorter in this soil zone, the cooler temperature and increased moisture are appropriate for a wider variety of cropping practices (Agriculture and Agri-Food Canada, 2000). The SOM is typically 4.5 to 5.5% but can be higher (8 to 10%) in the more fertile Black Chernozemic soils (Soils of Saskatchewan; http:www.soilsofsask.ca). Cereal crop yields are typically higher in the Black soil zones (Agriculture and Agri-Food Canada, 2000; Rehemuti, 2014). The grass species that are frequently seeded in this region include meadow bromegrass, smooth bromegrass, hybrid bromegrass, timothy, orchardgrass, sainfoin and alfalfa.

Gray, Dark Gray and Dark-Gray wooded soils are found in the Boreal Transition Ecoregion and encompass about 4.53 million hectares in the northern agricultural area, but only 45% of the Gray soils are cultivated (Agriculture and Agri-Food Canada, 2000; Rehemuti, 2014). The characteristics of this region are lower soil organic matter content (3.5 to 4.5%), higher moisture condition (484 mm) (Fuller, 2010), but a shorter growing season compared to Black soil zone (Soils of Saskatchewan; http:www.soilsofsask.ca).

2.3 Legume Species

2.3.1 Alfalfa (*Medicago Sativa* L.)

Alfalfa remains the most common and widely grown forage crop in western Canada with approximately 3.4 million ha (Statistics Canada, 2011). Alfalfa is an exceptional temperate forage legume yielding 3,556 kg ha^{-1} in the Brown soil zone, 7,101 kg ha^{-1} in the Dark Brown soil zone and 6,352 kg ha^{-1} in the Black and Grey soil zones (Saskatchewan Forage Council, 2007). Alfalfa is highly palatable and can have crude protein (CP) levels as high as 21% and digestible dry matter levels of approximately 71 % (Saskatchewan Forage Council, 2007). However, a management issue with alfalfa is that the legume causes bloat in grazing livestock.

Alfalfa has a higher feeding value compared to grass species. Alfalfa in the vegetative state has higher dry matter intake (DMI) characteristics and a higher animal production response per unit of DM ingested (Frame, 2005), due to the rapid passage of digesta out of the rumen, which stimulates appetite, a high concentration of soluble protein and adequate supply of minerals and vitamins (Allen, 1996; Popp et al., 2000).

Beef cattle weight gains of 1.0 to 1.5 kg d^{-1} (Popp et al., 1997), and 440 to 820 kg ha^{-1} (Burris et al., 1993; Sottie et al., 2014), when grazing alfalfa pastures under proper management are comparable to those achieved in confined feedlot systems (Popp et al., 2000; Sottie et al., 2014), but at a lower cost.

AC Yellowhead is an alfalfa cultivar (*Medicago sativa* subsp. *falcata* L.) which was developed at the Semiarid Prairie Agricultural Research Centre, Agriculture and Agri-Food

Canada (AAFC) Swift Current, SK, with the collaboration of Research Centres of AAFC in the Prairie Province. Yellowhead is a ‘‘falcata type’’ meaning that it is yellow flowered with sickle shaped seed pods (Mcleod et al., 2009). According to Saskatchewan Forage Council (2007), creeping root-type alfalfa yields approximately 3,670 kg ha^{-1} in the Brown soil zone, 7,681 kg ha^{-1} in the Dark Brown soil zone and 6,352 kg ha^{-1} in the Black and Grey soil zones. Yellowhead alfalfa has semi decumbent growth characteristic, slow regrowth and a deep-set crown (McLeod et al., 2009). They are interseeded into a mixed-grass rangeland improved persistence (Bittman and McCartney, 1994), increases forage production and quality (Mortenson et al., 2005; Hendrickson et al., 2008), and carbon sequestration (Mortenson et al., 2004).

2.3.2 Sainfoin (*Onobrychis viciifolia* Scop.)

Sainfoin is a non-bloating forage legume (contains condensed tannins) which produces biomass yield of 80 to 90% of alfalfa (Aasen and Bjorge, 2009). Jefferson et al. (1994), based on the 5-yr study at Swift Current, Saskatchewan concluded that the monoculture sainfoin yielded 85% of the monoculture alfalfa which is close to the reported sainfoin yield potential of 80% of alfalfa yield at Lethbridge, Alberta (Goplen et al., 1991). In contrast, Tilley et al. (2008), found that first harvest yields of sainfoin were greater than alfalfa (first harvest yield) but subsequent yields were lower relative to alfalfa. Sainfoin yields approximately 1,846 kg ha^{-1} in the Brown soil zone, 6,738 kg ha^{-1} in the Dark Brown soil zone and 5,875 kg ha^{-1} in the Black and Grey soil zones (Saskatchewan Forage Council, 2007).

Sainfoin is highly palatable to all types of livestock with an average digestibility of 63% and CP content of 18% during early bloom (Saskatchewan Forage Council, 2007). The nutritive value of sainfoin and alfalfa are comparable however, sainfoin hay was found to be higher in nitrogen-free extract, total digestible nutrients (TDN) and phosphorus, while lower in crude fibre, CP and calcium (Ca) compared to alfalfa hay (Krall, 1979). Similarly, the CP concentration, Ca and sodium content of sainfoin are lower than that of alfalfa (Spedding and Diekmahns, 1972; Acharya et al., 2013), when compared at the same morphological stage.

Earlier studies have reported an average daily gain (ADG) of 0.80 and 0.86 kg d^{-1} for steers grazing pure sainfoin pastures (Marten et al., 1987; Mowrey et al., 1992), which are comparable to gains in cattle grazing alfalfa pastures.

New types of sainfoin have been developed in the U.S. and Canada, as sainfoin breeding programs have selected for increased disease resistance, improved nodulation, nitrogen fixation, and increased dryland (single-cut) and irrigated (multi-cut) yields. These cultivars include Melrose, Nova, AC Mountainview and AC Glenview (Canada), Fakir (France), Eski, Remont, Renumex, Shoshone and Delaney (U.S.), Emry (Hungary), Zeus and Vala (Italy) and Othello (Australia).

'Nova' is more vigorous and taller than Melrose, Eski and Remont, and regrowth is comparable to Melrose and Eski but slower than Remont (Hanna, 1981). Nova has 7% greater forage yield and winter hardiness than Melrose (Goplen et al., 1991; Sottie, 2014). Acharya (2015), reported a 3-yr average yield of 6,004 kg ha^{-1} at Swift Current and 6,530 kg ha^{-1} at Saskatoon for Nova sainfoin, and acid detergent fibre (ADF) of 35.2%, neutral detergent fibre (NDF) of 39.8% and CP of 22.7%.

AC Mountainview sainfoin out yielded Nova sainfoin approximately 42% in pure stands and 39% in mixed stands with alfalfa (Acharya, 2015). The author reported the mean total annual dry matter yield (DMY) of this cultivar under rain-fed conditions over 12 site years was 7.52 t ha^{-1} and 12.97 t ha^{-1} over 6 site yrs under irrigation. It yielded a 3-yr average of 4,542 kg ha^{-1} at

Swift Current and 7,021 kg ha^{-1} at Saskatoon. The legume also recorded a mean ADF of 30.5%, NDF of 35.1% and CP of 24.0 percent.

‘Shoshone’ sainfoin was developed for high tolerance to northern root-knot nematode when compared to ‘Remont’. Shoshone has good drought tolerance, winter hardiness, and is also resistant to alfalfa stem nematode (Hybner, 2013). The cultivar produced an average 3-yr biomass yield of 10,910 kg ha^{-1} at Lethbridge, Alberta (Sottie, 2014).

‘Delaney’ sainfoin was developed as a multi-cut variety to replace the older Remont variety (Hybner, 2013). Under irrigation, Delaney had higher yields than Shoshone, Remont, and Eski sainfoin, and cultivars of birdsfoot trefoil (*Lotus corniculatus* L.) and cicer milkvetch (*Astragulus cicer* L.) (Tilley et al., 2008). Under dryland conditions, Delaney proved superior to Eski but similar to Remont (Hybner, 2013). Delaney produced an average 3-yr biomass yield of 11,275 kg ha^{-1} at Lethbridge, Alberta (Sottie, 2014)

2.3.3 Cicer Milkvetch (*Astragalus cicer* L.)

Cicer milkvetch is a long-lived, perennial non-bloat forage legume suited for either hay or pasture. Biomass yields of cicer milkvetch are generally comparable to those of alfalfa in areas with longer growing seasons (Baldridge and Lohmiller, 1990). Cicer milkvetch yields approximately 1,676 kg ha^{-1} in the Brown soil zone, 4,312 kg ha^{-1} in the Dark Brown soil zone and 5,295 kg ha^{-1} in the Black and Grey soil zones (Saskatchewan Forage Council, 2007).

The moisture content of cicer milkvetch is typically 4 to 8% greater than alfalfa or sainfoin (Loeppky et al., 1996). The CP levels of 15 to 30% of cicer milkvetch are equal to or exceed other legumes, due, in part, to the high leaf to stem ratio of cicer milkvetch (approximately 40% greater than alfalfa) and cicer milkvetch’s ability to retain leaves during drying and baling (Baldridge and Lohmiller, 1990; Loeppky et al., 1996). Stands of cicer milkvetch resist overgrazing because of its vigorous sod forming rhizomes and recovery from grazing is rapid; however recovery after cutting for hay is relatively slow (Baldridge and Lohmiller, 1990). Close grazing stimulates growth from the base of lower leaves, crowns and rhizome buds thereby increasing stand density following grazing. However, cicer milkvetch is not as palatable to grazing heifers due to photosensitization (Marten et al., 1987), and less acceptable to sheep (Marten et al., 1990), compared to other forage legumes.

AC Veldt cicer milkvetch was developed in Canada at the Lethbridge Research Center, Alberta. AC Veldt cicer milkvetch is a synthetic cultivar developed for improved seedling vigor and forage yield (Acharya, 2009). AC Veldt cicer milkvetch is intended for use as a pasture legume or in mixed stand with grasses for hay and silage. This cultivar yielded 122% of Oxley in the Gray-Wooded soil zone and 110% in the Brown and Black soil zones, respectively (Acharya, 2009). The scientist also reported AC Veldt cicer milkvetch out yielded Oxley by 15% and 27% under non-irrigated and irrigation conditions, respectively in western Canada.

AC Oxley I cicer mikvetch yielded 2,987 kg ha^{-1} and 964 kg ha^{-1} at Saskatoon and Swift Current, respectively, whereas Oxley II cicer milkvetch yielded 2,192 kg ha^{-1} and 988 kg ha^{-1} at Saskatoon and Swift Current, respectively (Acharya, 2001).

2.3.4 Canadian Milkvetch (*Astragalus canadensis* L.)

Canadian milkvetch is a native legume species that can be found from British Columbia to Quebec and south into Colorado, Virginia and Texas where soil moisture is available and there is full or partial sunlight (Jensen and USDA NRCS, 2002; Hilty, 2007). Canadian milkvetch has the ability to fix N and reduce erosion because of the extensive rooting system

(Hilty, 2007; Kusler, 2009). Kusler (2009), reported an average yield of 3,980 kg ha^{-1} for Canadian milkvetch at AAFC SCRDC site. It is not uncommon for Canadian milkvetch leaves to begin yellowing (senescing) early in the growing season (Kusler, 2009). Canadian milkvetch is palatable and nutritious for livestock and wildlife during certain periods throughout the growing season (Stubbendieck and Conard, 1989; Jensen and USDA NRCS, 2002).

However, there are some concerns with toxic compounds like 3-nitroproprionic acid, 3-nitropropanol and nitrotoxin that can reduce energy availability to the brain and result in death (Burrows and Tyrl, 2006). There are mixed findings about Canadian milkvetch toxicity, as some research has shown that unlike many milkvetches and locoweeds that are poisonous, Canadian milkvetch is non-toxic (Hilty 2007). However, work done with Canadian milkvetch at Brookings, South Dakota and Swift Current, Saskatchewan showed that toxicity levels ranged from non-toxic to extremely toxic, which can be affected by genetics, plant maturity and environmental condition (Kusler, 2009). Canadian milkvetch has a short life expectancy of only 3 to 4 years, and persistence of Canadian milkvetch can be improved with proper management such as grazing or mowing to prevent seed head formation (Jensen and USDA NRCS, 2002).

2.3.5 Purple Prairie Clover (*Dalea purpurea* Vent.)

Purple prairie clover is a native, warm-season, perennial legume that grows in an upright form and can reach heights between 30 to 90 cm (Wynia, 2008a). The author suggested that purple prairie clover can grow on prairies, plains, and hills in soils and thrives in 300 to 380 mm precipitation zone. Purple prairie clover has the ability to fix atmospheric N, hence use for re-vegetation and prairie restoration in mixed stands is important (Kusler, 2009). Although purple prairie clover has relatively poor forage yields (McGraw et al., 2004), which decreases and disappear under continuous grazing (Stubbendieck and Conard, 1989), when compared to other native legumes, purple prairie clover yielded a biomass between 1,800 and 2,100 kg ha^{-1} in Nebraska (Beran et al., 1999). Mixture of purple prairie clover with adapted warm-season grasses as forage crops appeared promising (Posler et al., 1993). According to Wynia (2008a), mechanical scarification or a laboratory scarifier is acceptable and necessary to aid germination of this species.

Purple prairie clover is an excellent forage for livestock and wildlife because of the high protein, palatability and digestibility (Posler et al., 1993). However, purple prairie clover may cause bloat if consumed in large quantities in grazing animals in the pre-bud or bud stage (Stubbendieck and Conard, 1989; Wynia, 2008a). A 2-yr study in central Missouri by McGraw et al. (2004), reported neutral detergent fibre of 47.3%, acid detergent fibre of 29.3% and crude protein of 15.2% for purple prairie clover harvested at early flowering stage. Purple prairie clover contains condensed tannins (CT) of 56.8, 65.4 and 84.0 g kg^{-1} at the vegetative, flowering and seed maturity stage, respectively (Li et al., 2014). The authors reported that CT in PPC possess strong antimicrobial activity against *Escherichia coli* O57:H7 when grazed by ruminant animals.

2.3.6 White Prairie Clover (*Dalea candida* Michx. Ex Willd)

White prairie clover is a native, warm season, herbaceous, perennial legume in the Great Plains. White prairie clover is found growing primarily on well drained sandy, gravelly, and silt soils, rarely on clay or lowland sites with 250 to 450 mm of annual precipitation (Wynia, 2008b). The author reported that white prairie clover fixes atmospheric N, and is used in reclamation of disturbed lands, range renovation and prairie restoration projects (Wynia, 2008b). Biomass yield of white prairie clover is 43% lower compared to purple prairie clover (McGraw et al., 2004). According to Stubbendieck and Conard (1989), germination of white prairie clover can be improved by scarification, and this species will decrease and disappear under continuous grazing.

White prairie clover is a palatable and nutritious forage for all classes of livestock with NDF of 50.7%, ADF of 27.5% and CP of 12.7% in central Missouri harvested at early flowering stage. Wynia (2008b) suggested that white prairie clover should improve forage digestibility in mixed stands with native warm season grasses.

White prairie clover contains condensed tannins (CT) of 9.2, 43.2 and 47.0 g kg^{-1} at the vegetative, flowering and seed maturity stage, respectively (Li et al., 2014). The fact that WPC contains high amount of CT, especially in the flower fraction may stimulate increasing attention to this native legume.

2.4 Grass Species

2.4.1 Hybrid Bromegrass (*Bromus riparius* Rehm x *Bromus inermis* Leyss)

Hybrid bromegrass was produced by crossing smooth bromegrass and meadow bromegrass followed by several cycles of recurrent selection for plant vigor, floret fertility, reduced rhizome production and good fall regrowth (Ferdinandez and Coulman, 2001). Hybridization can be obtained under controlled greenhouse intercrossing, however natural hybrids appear not to occur under field conditions due to an earlier flowering period (6-10 days) for meadow bromegrass (Knowles et al., 1993; Ogle et al., 2012b). The resulting hybrids share characteristics of both parental species (Ferdinandez and Coulman, 2001; Coulman, 2004). The goal was to produce a multi-purpose grass that possessed intermediate characteristics such as faster regrowth and a higher canopy that could be used for both hay and pasture production (Coulman, 1998; Kusler, 2009).

Hybrid bromegrass (like other bromegrasses) is adapted to the Gray Wooded, Black and Dark Brown soil zones and irrigation areas in the Canadian prairies. Hybrid bromegrass goes dormant during severe dry periods but grows quickly when there is moisture again (Aasen and Bjorge, 2009). In simulated grazing experiments (three cuts per season), hybrid bromegrass outperformed smooth bromegrass but not meadow bromegrass; while in a hay system (two cuts per season), the hybrids outperformed meadow bromegrass but not smooth bromegrass (Coulman and Knowles, 1995). Hybrid bromegrass yields approximately 6,500 kg ha^{-1} in the Dark Brown soil zone and 6,318 kg ha^{-1} in the Black and Grey soil zones (Saskatchewan Forage Council, 2007).

Hybrid bromegrass produces lower ADF and NDF concentrations than either smooth bromegrass or meadow bromegrass at similar stages of maturity (Coulman, 1998). As the plants reached the heading stage, NDF was lower for meadow bromegrass than for either smooth bromegrass or hybrid bromegrass and the CP was lower in the hybrid population than for either of the other two species (Ferdinandez and Coulman, 2001). Once the three types of brome reached the anthesis stage, there was no difference ($P > 0.05$) in NDF, ADF or CP (Ferdinandez and Coulman, 2001).

Grazing data from Melfort and Swift Current, Saskatchewan showed that hybrid bromegrass produced equal or better average daily gains, pasture yields and carrying capacity as meadow bromegrass (Coulman 1998; Kusler, 2009). Thompson et al. (2003), reported an ADG of 0.74 to 1.62 kg d^{-1} during the summer grazing trials of steers on hybrid bromegrass at WBDC site. The authors also reported the greatest total beef production (TBF) (160 and 185 kg ha^{-1})

were from the hybrid bromegrass pastures than the smooth bromegrass, meadow bromegrass and crested wheatgrass pastures.

AC Success is a hybrid bromegrass cultivar developed from a backcross of a hybrid brome population with smooth bromegrass (as the female parent). AC Success contains the smooth bromegrass cytoplasm, which makes it more “smooth-brome like” in appearance than AC Knowles hybrid bromegrass (Coulman, 2004; 2006). AC Success was developed at the Saskatoon Research Centre of Agriculture and Agri-Food Canada. Coulman (2006) reported biomass yield of 2,640 kg ha^{-1} in the Brown soil zone and 5,670 kg ha^{-1} in all non-irrigated sites. AC Success produced biomass yield of approximately 103% of Fleet meadow bromegrass, but only 96% of Carlton smooth bromegrass. The author suggested this cultivar to be adapted to Brown soil zone of the prairies due to relatively poor performance under irrigation. AC Success has faster re-growth potential which was similar, or superior to, Paddock meadow bromegrass and Knowles hybrid bromegrass in dry matter yield on most sampling dates. AC Success hybrid bromegrass has an average ADF of 28.3%, NDF of 49.1% and CP of 12.2 percent.

2.4.2 Russian Wildrye (*Psathyrostachys junceus* [Fisch.] Nevski)

Russian wildrye is an early spring-growing, long-lived perennial bunchgrass. Russian wildrye provides good grazing in spring and from late summer through late fall (Sedivec et al., 2007). Russian wildrye generally produces modest yields compared to most other introduced tame grasses. Russian wildrye yields relatively better as pasture than as hay (Aasen and Bjorge, 2009). The authors reported that biomass yield of this grass species is closely related to soil moisture in the spring months and productivity decreases in older stands. Although, Russian wildrye is adapted to Brown and Dark Brown soil zones in western Canada, yields (DM) are approximately 2,193 kg ha^{-1} in the Brown soil zone, 4,715 kg ha^{-1} in the Dark Brown soil and 3,852 kg ha^{-1} in the Black and Grey soil zones (Saskatchewan Forage Council, 2007). However, Russian wildrye can be difficult to establish as seedlings are quite weak and compete poorly against other plants (Lawrence and Heinrichs, 1977; Popp, 1995). Seedlings are slow growing and weak and require more time to establish compared to many other introduced grass species (Ogle et al., 2012a).

Russian wildrye's nutritional quality is optimum from late summer through late fall (Sedivec et al., 2007). In addition, Russian wildrye has the ability to retain higher protein content than most grasses after maturity thereby making it palatable to all classes of livestock in late summer through to winter (Ogle et al., 2012a). Crude protein levels of 5 to 7% can be expected in late fall through winter (Sedivec et al., 2007). Russian wildrye has an average digestibility of 66% and crude protein of 14% in the early summer (Saskatchewan Forage Council, 2007).

Tom Russian wildrye was developed by the Swift Current Research Development Centre of Agriculture and Agri-Food Canada (AAFC), Swift Current, Saskatchewan. McLeod et al. (2003), reported Tom is well adapted to the semiarid prairie region and therefore available to the cattleman in this region as a summer, fall and early winter pasture. Tom Russian wildrye yielded higher compared to Swift and Tetracan cultivars in the Brown and Dark Brown Soil zones of Saskatchewan. Tom Russian wildrye yielded an average of 3,376 kg ha^{-1} at Swift Current, Saskatchewan and 4,020 kg ha^{-1} at Mandan, North Dakota which were 19 and 15% more herbage than the cultivars Swift and Tetracan, respectively, in 10 site years of testing on irrigation at Swift Current. On average, in 4 site years of trials at Saskatoon, Tom yielded 15 and 16% and 8 and 22% more herbage dry matter than the check cultivars Swift and Tetracan when cut at hay and pasture stages of development, respectively.

2.4.3 Meadow Bromegrass (*Bromus riparius* Rehm.)

Meadow bromegrass is a long-lived bunch grass that is considered an excellent option for re-establishing tame grass pastures. Meadow bromegrass has shorter rhizomes and less aggressive compared to smooth bromegrass (Ferdinandez and Coulman, 2001; Sedivec et al., 2007; Kusler, 2009). Sedivec et al. (2007), observed that meadow bromegrass produced 30% of its total biomass by mid May and 47% by early June. Meadow bromegrass is adapted to the Black, Gray Wooded and higher precipitation areas of the Dark Brown soil zone (Saskatchewan Forage Council, 2007; Aasen and Bjorge, 2009). The authors reported that meadow bromegrass yields approximately 3,431 kg ha^{-1} in the Brown soil zone, 5,306 kg ha^{-1} in the Dark Brown soil and 4,596 kg ha^{-1} in the Black and Grey soil zones.

Meadow bromegrass in the vegetative stage tends to have higher fibre levels and slightly lower protein levels than SBG but these differences become less evident as plants mature (Coulman, 1998; Kusler, 2009). The leaves of meadow bromegrass stay green well into the fall and are tolerant of early frosts, making it an ideal crop for stockpiled dormant season grazing. Stockpiled regrowth from early July retains its nutritive value well into winter and spring with less yield and quality than most grass species (Aasen and Bjorge, 2009).

AC Admiral meadow bromegrass was bred in Canada by Agriculture and Agri-Food of Saskatoon Research Center for the harsh environment. Admiral meadow bromegrass yielded (dry matter) 6,129 kg ha^{-1} in the Black-Grey soil zone, 9,496 kg ha^{-1} in the Dark Brown soil zone and 2,636 kg ha^{-1} in the Brown soil zone (Coulman, 2009). Highest relative yield potential was reported in Brown (140%) and Dark Brown (105%) soil zones in the Western Forage Testing System Trials from 2005-2007 (Coulman, 2009).

2.5 Forage Grass-Legume Mixtures

Forage grasses require a regular supply of N for their optimum growth, development, yield and quality. The legumes in the mixtures symbiotically fix atmospheric N and increase plant-available soil N by improving net mineralisation of litter and root materials. This change can particularly increase grass production when soil N is limited (Mendoza et al., 2016). Forage legumes usually have a higher yield than forage grass species and are rich in protein, whereas forage grass species have higher carbohydrate content (Mendoza et al., 2016). Therefore, both the yields (100%) and the nutritional values (31 to 46%) of grass-legume mixtures are higher than of monocultures of legumes or grass species (Sleugh et al., 2000).

According to Dhakal and Islam (2017), 50% proportion of legume in a mixed stand is an optimal condition for improved yield, forage quality and stand persistence. This produced 37% more forage yield than N applied (150 kg N ha^{-1}) monoculture meadow bromegrass (32,771 vs. 23,943 kg ha^{-1}), and 42% more than alfalfa (32, 771 vs. 23,089 kg ha^{-1}) and 20% more CP values than monoculture alfalfa over a 3-yr period. The scientists concluded that at least 25% of legumes in mixed stand produced higher forage yield and quality than monoculture alfalfa and N fertilized grasses.

Grass-legume mixtures is the most effective and least costly method of minimizing pasture bloat (Majak et al., 2008), particularly for beef herds grazing over large areas under a continuous grazing system. The scientists suggested that 50% legumes in mixed stand as the maximum bloat safe level. In this situation, the animals are able to graze grass and alfalfa at the same time thus preventing bloat.

The total response to fertilizers of a grass-legume mixture varies from the response of individual species in a pure stand. Components of a mixture respond differently to a nutrient and interact differently with each other. Consequently, management practices, including fertilizer application can cause a sward to become legume dominant or grass dominant. Several factors can determine the dominant type, but the most important factor is competition for light (Walton, 1983), and for grasses, plant height, density and N supply are all correlated. Increased N application will increase grass yields; this increase gives a higher leaf area of grass to overshadow the lower-growing legume canopy and reduce the light intensity at legumes leaf surface (Bates, 1993). This, in turn, reduces photosynthesis and slows legume growth. However, according to Lissbrant et al. (2009), application of K and P fertilizers have been shown to increases the persistence of legumes in grass-legume mixtures. Ogle et al. (2012b), in a grass-legume mixture study observed that meadow bromegrass was favored by N while P favors the legume.

A study by Walton (1983), have shown that competition for K also exists in a grass-legume mixture. This influences growth rates of grasses relative to legumes because of a decrease in light intensity of the legume. In addition, the cation exchange capacity of legumes is higher (roots absorb large amounts of calcium) than that for grasses, hence unable to successfully compete with grasses for K for rapid growth and longevity. In the Aspen Parkland, bromegrass frequently dominates alfalfa, so management strategies are important to establish a competitive balance between legumes and grasses component (Pearen et al., 1995).

With intake maximization as a goal in grazing studies, grazing ruminants should prefer legumes over grasses, because legumes are easier to masticate and digest, thereby clearing the rumen faster (Soder et al., 2009). Grazing studies have demonstrated that cows and sheep have consistently preferred a diet containing approximately 50 to 70% white clover (*Trifolium repens* L.) when offered adjacent monocultures of perennial ryegrass (*Lolium perenne* L.) and white clover, despite changes in the proportional area of the two species offered (Parsons et al., 1994; Rutter, 2006). These preferences have shown a distinct diurnal pattern with clover being preferred in the morning with an increasing preference for grass in the afternoon (Parsons et al., 1994; Rutter, 2006). For example, it has been observed that grazing ruminants may increase consumption of grasses in the evening due to the higher fibre content to maintain ruminal fill overnight (Newman et al., 1995), or because the sugar content of grasses increases throughout the day, potentially making them more palatable in the afternoon compared to the morning (Soder et al., 2009).

2.6 Techniques for Estimating Forage Production

2.6.1 Vegetation Weight Determination by Clipping

Estimation of vegetation weight by clipping is one of the most common and important methods for determining forage biomass yield in grazing studies. This method allows to estimate the annual growth of herbage with the use of permanent grazing enclosures and-or total growth and regrowth (cumulative) throughout the grazing period (Ward, 2009).

In most grazing studies, quadrats are often the subsampling unit used to determine herbage weight within a given area by clipping the contents. The number of samples that are taken on a pasture is of importance to reduce error, when estimating herbage mass. An alternate method to the quadrat method for biomass estimate is the cage technique. According to Klingman et al. (1943), this technique involves random placement of cages prior to grazing and clipping the forage inside the cage when grazing is finished to give an estimate of growth during the grazing period. The technique assumes that (i) variations in biomass yield between the herbage in a cage (protected area) and nearby grazed area (unprotected area) is equal to the forage consumed; and (ii) the difference in forage inside a cage (protected area) at a given date and forage outside a cage (unprotected area) at a previous clipping date is equal to the growth or regrowth that occurred in the elapsed period. This technique has been associated with large error since grazing by ruminant livestock is not uniform and variations in soil and herbage between the caged and non-caged areas (t' Mannetje, 1978). t' Mannetje (1978) suggested transient cage method as a more accurate method to represent biomass yield of grazed sward. This technique involves movement of cages throughout the grazing period rather than left in one site thereby accounting for previously grazed area as well as losses due to trampling and fouling (t' Mannetje, 1978).

2.6.2 Height and Density of Vegetation

Several grazing studies have developed equipment to estimate the pasture yield using the height and density of vegetation technique (Earle and McGowan, 1979; Crosbie et al., 1987). This equipment includes simple measuring sticks, weighted discs, rising or falling disc meters and probes. However, t’ Mannetje (2000), suggested that the ‘drop-disc’ or ‘weighted disc’ are commonly used to estimate height and density of vegetation. Vegetation height is measured using round or square discs on central rods to measure compressed sward height. The height at which the disc meets resistance from the forage is recorded and used to estimate forage yield based on previous calibration data. For a more accurate prediction of biomass yield, the ground cover or sward density is combined with the vegetation height. This method is rapid, however, Douglas and Crawford (1994), have proven that accuracy is adversely affected when plant senesce.

2.6.3 Ocular Estimations

This method involves the visual estimation of biomass yield in an area. It is a rapid and non-destructive technique but requires extensive training prior to visual estimation. The visual estimation is often validated by actual measurement (clipping) as a check to adjust estimate and improve accuracy (t' Mannetje, 1978). The subjective nature of this technique makes it feasible only in a large-scale trial where labor is limited.

2.6.4 Estimation and Double Sampling Technique

This technique combines both the non-destructive techniques and destructive techniques. Biomass yield is first estimated by weight (visual estimate) and then clipping a certain percentage of quadrats to determine actual biomass yield values. With the aid of regression analysis, estimated weights are denoted as the dependent variable and actual weights as the independent variable, to adjust values by a regression equation (Cook and Stubbendieck, 1986). This technique is reasonably accurate, saves time and can be used to estimate large sample size relative to the destructive technique (Cook and Stubbendieck, 1986). Disadvantages include the need to develop estimation skills and high degree of concentration needed by the estimator. Cook and Stubbendieck (1986), reported that variances for estimates were lower than those clipped quadrats. Estimators tend to underestimate quadrats with high herbage weight and overestimate those with low herbage weight.

2.6.5 Prediction Based on Precipitation

Weather conditions prior to or early in the growing season have been studied to predict forage yields. For example, it was concluded from a 14-yr study at the Squaw Butte Station in southeastern Oregon that weather could be used to accurately predict crested wheatgrass

(*Agropyron cristatum*) production (Sneva, 1977). The researcher reported that the highest correlations were between May to July precipitation plus March to May temperatures for predicting matured yields. Mean February temperature with March precipitation accounted for 83% of the variation in spring yield. Crested wheatgrass yields by May 15 varied from 75 to 490 kg ha^{-1} and averaged 332 kg per hectare (Sneva, 1977). Similar procedures were used successfully for estimating annual herbage production on southwestern Idaho range (Hanson et al., 1983).

On salt-desert shrub range in western Utah, grazed only during the winter, the 1935 to 1947 average annual air-dry herbage production was 246 kg ha^{-1}, ranging as high as 525 to 840 kg per hectare (Vallentine, 2001). The researcher concluded that prediction equations could circumvent the need of sampling vegetation to estimate cumulative herbage production by the beginning of the dormant grazing season. Their prediction equation utilized the previous 12-month precipitation to predict the October standing crop of forage and was found to be reliable during 102 to 279-mm rainfall years ($r = 0.94$). Where data are insufficient to estimate formula relationships between weather and forage production, subjective evaluations may be the best information that is currently available. However, only experienced grazing managers are apt to be successful in this.

2.7 Techniques for Estimating Botanical Composition

Clipping and sorting technique involves harvesting of vegetation within quadrats and hand sorting and weighing each grass and legume species component. Another approach is to cut individual plants of different species separately, dry and weigh. This technique is the appropriate technique if the botanical composition of the grassland is relatively simple and materials can be adequately identified (Whally and Hardy, 2000; Gamage, 2014). However, this is time consuming if there are more than two or three important species in the sample or when large numbers of samples are to be analyzed (Whally and Hardy, 2000).

Deubenmire frame technique involves the use of a quadrat frame which is marked along the tape at the specified intervals, estimate the canopy coverage of each plant species (Daubenmire, 1959; USDI Bureau of Land Management, 1985). Canopy coverage estimates can be made for both perennial and annual plant species. This technique is relatively simple and rapid to use; however, it cannot be used to calculate rooted frequency.

Near-infrared reflectance spectroscopy is available for analysis of organic, some mineral components in forage (Gamage, 2014), and species composition of forage samples (Wachendorf et al., 1999). Forage samples are harvested then dried, ground, and reflectance spectra are determined. This method is relatively rapid when compared to clipping and sorting technique, however, appropriate calibration equations is critical to the success of the procedure (Whally and Hardy, 2000).

2.8 Methods for Determining Diet Nutrient Composition

Arnold and Dudzinski (1978), and Popp et al. (1999), suggested that estimation of nutrient quality in grazed pasture is difficult because dietary selection occurs between and within plant species. In support (t' Mannetje, 1978; Cook and Stubbendieck, 1986), have recommended that techniques such as hand-plucking or esophageal fistulation should be used for the estimation of nutrient quality of pastures. Other techniques include stomach analysis, fecal analysis fistula and clipping techniques (Judy, 2014).

Hand-plucking technique (Willis de Vries, 1995; Bonnet et al., 2011), consists of manually selecting plant materials to estimate bite mass by simulating the bite size, plant species and parts cropped by the animals. Several studies (Meuret et al., 1986; Hudson and Frank, 1987) have shown that combination of bite-count and hand-plucking are used to estimate short-term intake and diet composition of grazing ungulates on rangelands. This technique is simple and inexpensive and can be validated with esophageally fistulated animals (Bonnet et al., 2011; Judy 2014). Hand-plucked samples collected represent ingested forages by grazing animals on individual paddocks after hours of observation (Cook and Stubbendieck, 1986).

Fistula technique: Edlefsen et al. (1960), reported that grazing animals select their diet from a variety of plant species. Due to cattle selectivity, allowing the cattle to sample the plant species they prefer would help eliminate the aspect of human bias in diet sampling. Two different fistula techniques are common for collecting diet samples for grazing animals which are esophageal and ruminal.

Clipping quadrats is also a relatively inexpensive method for determining quality of the available forage (Judy 2014). Clipped samples are free from salivary contamination which can occur with other methods of sampling. If sampling occurs during the dormant season, then clipping samples may be an effective measure of available nutrients because they more closely match the value of the actual cattle diets (Wallace et al., 1972). Jefferies and Rice (1969), showed that in drier years clipped sample protein content may be comparable to the actual diets of the animal which could be caused by decreased animal selectivity. Clipping quadrats to predict diet quality have a high potential for committing error such as misrepresenting actual diet and hence, should be used with caution when used to estimate diet nutrient composition (Edlefsen et al., 1960; t' Mannetje, 1978; Cook and Stubbendieck, 1986; Popp et al., 1999).

2.9 Forage Nutritive Value

The composition of forage is highly influenced by many factors such as soil type, climate, plant variety, extent of insect infestation, and presence of diseases (Judy, 2014). The author reported that physiological and morphological stage of development of grass and legume species is the primary factor determining forage quality. According to McGeough et al. (2018), as plants mature over the grazing season, the nutritive value of forage decline as a result of simultaneous decrease in CP concentration and digestibility, and increase in NDF concentration. The authors added that as a consequence of the decreased forage quality, stockpile grazing has traditionally been used primarily for beef cows in mid gestation.

Measurement of forage quality can be obtained from field grazing trials or by laboratory analysis or a combination of both. Grazing trials are practical means of indirectly evaluating forage quality, however, laboratory tests are commonly used to measure the nutritional level of the range forage (Cook and Stubbendieck, 1986).

2.9.1 Crude Protein (CP)

Crude protein is determined using the Kjeldahl and LECO techniques by analyzing the herbage to find the proportion of nitrogen in the dried sample and the result multiplied by 6.25. (Adesogan et al., 2000). The authors reported that the value 6.25 reflects the amount of nitrogen in protein; ammonia ions, nitrates and amides. However, the protein determined by these techniques is crude and not true protein, because the results include non-protein nitrogen, which can also be used by the rumen fauna and flora to build protein. True protein can be measured by using high-pressure liquid chromatography which will determine the individual amino acids in a sample. An alternative to the Kjeldahl technique is ninhydrin assay or colormetric techniques

(Adesogan et al., 2000). Although, ninhydrin assay is quite sensitive, the challenge of preparing reagent and use has limited the wide-spread usage of this technique. Colormetric methods can also be used to determine true protein concentration (Adesogan et al., 2000). This method requires pre-digestion or maceration of sample prior to analysis because it measures largely soluble nitrogen. This method requires standardization with another method such as the Kjeldahl method (Adesogan et al., 2000).

Higher crude protein concentrations are considered an indicator of higher forage quality (McGraw et al. 2004). According to Walton (1983), ruminant animals require 8% to 10% CP for maintenance and up to 15 % CP in the case of high- producing dairy cows. However, forages with less than 7% CP contents have been noted to have low intake by animals (Matejovsky and Sanson, 1995) and this reduction in intake is explained by the relationship between nutrient content, microbial CP requirements and digestibility.

2.9.2 Detergent Fibre

Cell wall content generally is regarded as the most important factor affecting forage utilization because it comprises the major fraction of dry matter and is correlated with forage intake and digestibility (Collins and Fritz, 2003).

Van Soest (1994), developed a procedure, which separated the total fibre fraction (neutral detergent fibre (NDF)) from the less digestible fibre fraction (acid detergent fibre (ADF)). According to Collins and Fritz (2003), neutral detergent fibre (NDF) is a measure of the amount of structural fibre or cell wall material in the plant and is often associated with animal intake. The NDF fraction is only partially digestible by the microorganisms in the rumen; thus, larger NDF values indicate poorer forage quality and lower animal intake (Collins and Fritz, 2003).

Neutral detergent fibre is the portion of the plant that remains after digestion in a neutral detergent solution and includes cellulose, hemicellulose and lignin, of which only cellulose and hemicellulose are partially available for digestion (Van Soest, 1994; Collins and Fritz, 2003). The nutritive availability of the cell wall or NDF fraction is not uniform among different forages. Neutral detergent solubles include sugar, soluble carbohydrates, pectins, protein, nonprotein nitrogen and lipids, which are readily and almost completely available to the ruminant animal (Van Soest, 1994). Further digestion of the NDF fraction with an acid detergent solution yields ADF, which is the sum of cellulose and lignin, of which lignin is indigestible (Van Soest, 1994). The ADF concentration is believed to be associated with forage digestibility and is used to calculate total digestible nutrient values (Collins and Fritz, 2003).

2.9.3 Lignin

Lignin is a non-carbohydrate substance in plants that resist digestion, and is deposited as maturation takes place, on the microfibrils and other cellulose structures in the secondary cell walls of plants (Walton, 1983). Lignin varies from about 2% of DM in young plant to 17% or more in fully matured plants (Walton, 1983). Although lignin has been extensively used in digestion studies as an internal marker, problems exist with fecal recovery, quantification and isolation which limit the ability to accurately determine diet digestibility (Van Soest, 1994). The author suggested that the challenges of recovering lignin may involve products containing more than true lignin since a variety of other materials are often inadvertently isolated as crude lignin.

Klason lignin technique is the mostly used method of lignin determination of woody species. This method involves the use of 72% H_2SO_4 to remove polysaccharides from the extractives-free wood through hydrolysis. The method is accurate however there are some loss through solubilization leading to lower values (Van Soest, 1994). Despite the low value of ADF-Klason lignin, Maillard polymers, leather and cutin are further recovered. Thonney et al. (1979), reported that use of permanganate lignin as an internal marker underestimated digestibility compared to the total fecal collection method by approximately 23.9% because of low fecal recovery of lignin. They concluded that it was an unreliable internal marker for estimating diet digestibility.

2.9.4 Digestibility

In vivo digestibility techniques measure the difference between amount of feed consumed and the amount excreted in the feces. Two unique techniques developed to measure dry matter digestibility *in vivo* are (i) the use of animal intake and total fecal output; and (ii) use internal markers found in the forage to relate dry matter digestibility to the chemical composition of the feces (fecal-index technique) (Coates and Penning, 2000). The intake and fecal output techniques favors housed animals where animals are fitted with a harness which collects voided faeces (Corbett, 1978; Coates and Penning, 2000), while the internal markers favor grazing studies. Some of the internal markers used in fecal-index technique are silica, chromogen, potentially indigestible cellulose, lignin, indigestible NDF and insoluble ash (Burns et al., 1994). One limitation of this technique is incomplete fecal recoveries, and the technique is mostly compared to indirect techniques such as *in vitro* and *in situ* for accuracy (Minson, 1990).

In-situ technique is estimated by incubating, previously weighed feed samples sealed in silk or nylon bags inside the rumen (Minson, 1990). Major sources of variations associated with this technique are by sample preparation, washing and drying procedure, bag type, pore size, individual animal and modeling (Adesogan et al., 2000). An additional challenge affecting *in situ* estimates of rumen digestibility is the accurate correction for particulate losses occurring through the pores of the *in situ* bag which may exaggerate the immediately soluble fraction and alter the degradation curve produced by modeling, as well as choice of an appropriate outflow rate (Adesogan et al., 2000).

The *in-vitro* technique, rumen-fluid pepsin method was initially developed by Tilly and Terry (1963), but modified methods include the pepsin cellulase technique and gas production technique (Adesogan et al., 2000). Of all the *in vitro* digestibility techniques, the rumen-fluid pepsin method is one of the most useful for predicting digestibility *in vivo* values for many forages (Adesogan et al., 2000). However, this method requires fistulated animals to obtain rumen fluid and a long incubation period (Adesogan et al., 2000). According to the researchers this may lead to variations in results due to the variability of the rumen fluid composition and activity between individual animals. This technique also assumes that the final residue left after *in vitro* digestion is like fecal material excreted by the animal; however, the presence of metabolic fecal nitrogen present *in vivo* will cause some differences between *in vitro* and *in vivo* estimates of digestibility (Adesogan et al. 2000). This technique is accurate for fresh forage samples only because of differences in the sample form, particle outflow, nitrogen supply to rumen microbes and the production of Maillard products when comparing *in vivo* to *in vitro* values (Adesogan et al. 2000).

In the absence of rumen fluid, Akhter et al. (1999), suggested that feces can be used as a source of inoculum for *in vitro* digestibility estimates. However, digestibility values were lower than that of rumen fluid. Another technique called the pepsin-cellulase technique is simple and highly repeatable, but it is expensive and requires a constant supply of cellulase of constant activity (Adesogan et al. 2000).

Near-infrared reflectance spectroscopy (NIRS) is spectroscopic technique to determine the digestibility of feed-forage samples. This technique is based on the association of chemical composition of the feed sample with absorption of certain wavelength regions of light (Adesogan et al., 2000). According to the researchers a prediction equation is developed between NIRS spectral data and laboratory results to predict the nutritive value of samples. It is a chemical reagent free, non-pollutant, non-destructive, accurate, fast, quantitative and qualitative evaluation of feedstuff. These advantages make it superior to other methods such as chemical, rumen fluid and enzymatic methods of predicting digestibility and energy values (Adesogan et al., 2000). The limitation of this technique is the cost of purchasing the equipment and the requirement for extensive calibrations (> 100 samples) (Adesogan et al., 2000).

2.10 Voluntary Feed Intake

Performance and productivity of stocker cattle is directly related to the quality and quantity of herbage consumed (Popp, 1995). However, Demment and Van Soest (1983), suggested that although diet quality is important, variation in voluntary forage DMI has been deemed the most urgent factor determining level and efficiency of ruminant productivity. In addition, studies by Hakkila et al. (1987), showed that data on diet quality without information on forage intake will poorly describe the nutritional status of grazing animals.

2.10.1 Physical Factors Affecting Voluntary Feed Intake

Body size of the grazing animal has a major effect on influencing the level of voluntary feed intake (Freer, 1981; Allison, 1985). Cattle (large ruminants) are likely to have greater DMI than sheep or goats (small ruminants) (Adams, 1987). Feed intake is commonly described in relation to metabolic $BW^{0.75}$ (body weight to the 0.75 power), the index for general metabolism, or as a percent of body weight. Cordova et al. (1978), estimated that most intake for cattle and sheep grazing rangelands of the western U.S. fall within the range of 40 to 90 g of dry matter per kg $BW^{0.75}$ or from 1 to 2.8% of body weight. However, Freer (1981), noted that voluntary intake usually must satisfy many other demands besides basal metabolism and that these may not be related to BW in the same way. The scientist reported that bigger cows had a higher absolute forage intake but a lower intake per unit of liveweight than smaller cows.

Forage availability is also a major factor influencing intake by grazing animals (Ruyle and Rice, 1996). According to the NRC (1987), the quantity of available forage is the first limiting factor. As grazing pressure increases and-or the plants mature, the animal is forced to consume plant parts with a slower rate and extent of digestion. Hunter (1991), concluded that when pasturage is abundant and of high nutritive value, daily feed intake may exceed 30 g dry matter per kg of liveweight and apparent digestibility of dry matter may exceed 65 percent. However, when only mature, senescent pasturage with low leaf content is available, intake can be as low as 10 g of DM per kg of liveweight and digestibility can be lower than 40 percent Hunter (1991).

The palatability of forage plants strongly influences the grazing animal’s intake level and selectivity whether or not choices are offered (Arnold and Dudzinski, 1978). Grovum (1987), ranked low forage palatability and an unfavorable protein: energy ratio over reticulo-rumen distention as the main factors limiting the intake of poor-quality roughage; with medium- and good-quality roughage, rumen distention was ranked as the priority factor. Walton (1983) provided rules of thumb for estimating daily forage intake by the ruminant animal based on forage quality (palatability and digestibility), including (i) 2.5% of the animal's liveweight for a top-quality forage, (ii) 2% for good-quality forage, and (iii) only 1.5% for low-quality forage.

The author concluded that intake is high when the grazed forages are palatable and low intake when grazed forages are less palatable. Similar to the above, Krysl et al. (1987) in a study demonstrated that cattle on blue grama (*Bouteloua gracilis*) range in New Mexico consumed forage at 2.2% of body weight during active plant growth but only 1.5% when plants were dormant.

Nitrogen deficiency of forages can also be a limiting factor affecting feed intake, net utilization of metabolizable energy (Wallace, 1984), and animal performance (Vallentine, 2001). Diet digestibility and rate of passage is reduced when the N requirements of rumen bacteria are not met (NRC, 1987). The fact that high-quality forage has fast rates of digestion and passage through the gastrointestinal tract, ruminants grazing these forages can increase their grazing time and their herbage intake per day. Immature, highly digestible, slightly laxative forages will decrease retention time and rumen fill and thus stimulate intake (Vallentine, 2001). Providing the swards and herbage allowances are not limiting, high-quality forage may permit ruminants to reach daily consumption levels equivalent to as high as 5% of their liveweight (Dougherty, 1991). Voluntary intake is higher for legumes than for grasses and for temperate than for tropical forages, with legumes having a lower resistance to breakdown during chewing and rechewing (Minson, 1990).

Finally, a study conducted by Thornton and Minson (1973), to determine the relationship between apparent rumen retention time, voluntary intake and digestibility discovered that intake of legumes was 28% greater than that of equally digestible grasses. The scientists explained that digestible organic matter (OM) content of rumen digesta for legume diets was 14% higher than that of grasses. The study concluded that digestible OM intake was closely correlated with retention time (r = 0.93) and retention time was controlled primarily by fibrous fractions of the feed.

2.10.2 Chemical Regulation of Feed Intake

Firstly, oropharyngeal receptors in the buccal cavity and throat are important in the animal's sensory perception of feed; there may be innate or learned responses to feeds with particular palatability characteristics (Forbes, 1986; 2007). Forbes (1986), suggested that a ruminant's jaw muscles become fatigued because they spend a long time chewing each day, leading to slowing of the rate and eventually to the cessation of grazing.

In addition, Forbes (2007), has shown that the capacity of the digestive tract, principally the rumen also can affect intake. Increases in the volume of other abdominal organs, such as abdominal fat or a pregnant uterus, can apparently cause compression of the rumen and a reduction in feed intake. Forbes (2007), concluded that there is a negative correlation between the weight of the abdominal fat and intake of herbage in cattle.

According to Van Soest (1994), it was suggested that voluntary intake is controlled by blood glucose levels. The stability of blood glucose concentration and the fact that blood glucose rises after a meal, then falls before the next meal is relative and not absolute (Forbes, 1986). Following the glucostatic theory, several researchers have studied whether infusion of glucose or short chain fatty acids would depress intake. Glucose had no effect whether given intraruminally, intravenously or intra-cerebroventricularly at a rate which approximated to the rate of glucose turnover in the body (Forbes, 1986). Short-chain fatty acids affect intake, however a mixture of short chain fatty acids in physiological proportions (0.55 acetate, 0.30 propionate, 0.15 butyrate) infused intra-ruminally during spontaneous meals had a dose-related effect on intake by sheep or goats and cattle (Forbes, 1986; 2007). Separate infusion of the three acids showed that the effect of the mixture was due mainly to acetate and propionate, however propionate is less effective than acetate (Forbes, 1986; 2007).

2.10.3 Thermostatic Control

"Animals eat to keep warm and quit eating to prevent hyperthermia" (Forbes, 2007). Temperature within the thermal neutrality zone of (-10 to 20°C) has minimal effect on voluntary intake, however, above 20°C intake is depressed particularly in the short run, with some acclimatization in the long run (Forbes, 2007). Hakkila et al. (1987), reported low productivity of research cattle on desert grassland ranges in southern New Mexico, despite good forage nutrient levels. This was then attributed to low intake resulting from high temperatures and associated reduced grazing time in summer but to low forage quality in late fall and winter.

2.10.4 Techniques for Estimating Voluntary Feed Intake

The herbage disappearance technique (Pearson, 1975; Smit et al., 2005), is regularly estimated by hand clipping and weighing the forage in the pasture or paddock before and after grazing. However, a “sward height meter” or “rising plate meter” or “disk meter” can also be used to estimate herbage density and height. Determination of feed intake can either be underestimated or overestimated depending on number of factors including the error associated with the estimate of initial and final yields of available forage, the proportion of forage offered that is ingested, unnoticed growth of herbage during the grazing period as well as losses from unseen trampled herbage, decomposition or insect activities (Corbett, 1978).

Short-term change in live-weight is another technique used to estimate grazing intake for a short term. This technique was developed by weighing sheep before and after grazing to estimate intake (Allden and Whittaker, 1970; Penning and Hooper, 1985). The sheep were fitted with bags to prevent loss of feces and urine, the sheep were then weighed and then allowed the sheep to graze for approximately one hour before they were re-weighed. Weight gains were adjusted for insensible weight losses and then the increase in live-weight considered an estimate of fresh herbage intake. According to Minson (1990), corrections are made for loss of body weight due to the excretion of feces, urine or insensible losses or gains in body weight due to water consumption.

Moreover, esophageal fistula and fecal output determination is one of the most direct method practiced estimating intake (Costigan and Ellis, 1988). The fistula is formed by surgically transecting the esophagus and inserting a cannula. During sampling the cannula is replaced by a collection device while the animal grazes to collect samples of ingesta and then the sample is analyzed for digestibility after grazing (Costigan and Ellis, 1988). An external marker, chromium sesquioxide (Cr_2O_3), can also be used, and is a sustained slow-release bolus to determine fecal output (Captec Ltd., Auckland, New Zealand) (Costigan and Ellis, 1988; Popp et al., 1997). This procedure however, is labor-intensive, costly and requires technical skills for excellent result (Van Soest, 1994; Popp et al., 1997).

Herbage intake may then be calculated using the following equation:

$$\text{Intake} = (\text{fecal output}) - (1 - \text{digestibility of herbage})$$

Intake of grazing ruminants can also be estimated by indirect methods, which are basically categorized into ratio techniques and index procedures (Cordova et al., 1978). Ratio techniques calculate digestibility and fecal output based on their ratio to an indigestible marker while for index procedures a regression equation is developed to relate digestibility or feed intake to some component in the feces (Cordova et al., 1978; Coates and Penning, 2000).

Individual animal DMI can be determined by natural indigestible plant components (internal markers) such as lignin, alkanes, or insoluble ashes, which are excreted in faeces or using external markers which are administered in known amounts (Cordova et al., 1978). Dry matter intake is then estimated based on the concentration of marker (natural and synthetic) in the plant and animal feces using the following equation (Coates and Penning, 2000).

$$I = (Fi-Fj) \times Dj - (Hi - (Fi-Fj) \times Hj)$$

Where, I = intake; Fi and Fj = concentration of natural and synthetic alkanes in faeces; Dj = dose rate of synthetic alkanes; Hi and Hj = concentration of natural and synthetic alkanes in forage.

Due to the technical nature and difficulties in estimating DMI practically in the above methods, some researchers have relied on prediction equations to estimate voluntary intake and resultant animal performance based on known forage, animal and environmental factors. The NRC model (National Research Council (NRC), 1996) from which the CowBytes beef ration balancer (Alberta Agriculture, Food and Rural Development) was developed is an example of a prediction equation used by most researchers and producers in western Canada. Data derived from models and prediction equations is only as accurate as the data entered the equations.

Another prediction equation is referred to as Minson’s equation (Undi et al., 2008). This equation utilizes body weight (BW) and average daily gain (ADG) to calculate DMI for individual animals in each period for each paddock. The equation is as follows (Minson and McDonald, 1987; Undi et al., 2008):

$$\text{DMI (kg d}^{-1}\text{)} = (1.185 + 0.00454\text{BW} - 0.0000026\text{BW}^2 + 0.315\text{ADG})^2$$

Where BW= body weight (kg) and ADG = average daily gain (kg d^{-1}).

2.10.5 Forage Utilization

Forage utilization as defined by Hodgson (1990) and Vallentine (2001) is the proportion of the current year's forage production (biomass) that is consumed and-or destroyed by grazing animals. The determination of the forage utilisation is important in grazing studies to regulate animal stocking rates that allows plants to recover from grazing and restore vegetation to its previous condition.

A number of techniques that can be used to estimate forage utilization (degree of use) includes weight before and after grazing, cage comparison method, ocular estimation, stubble height class, height-weight and others (Cook and Stubbendieck, 1986).

2.11 Grazing Animal’s Behavior and Performance

Grazing behavior is important because of the immediate effect on animal’s production, pasture composition and productivity. Studying grazing behaviour enables livestock producers to manage pastures for improved productivity and sustainability (Coates and Penning, 2000).

Most grazing studies have shown that a major grazing period begins at about dawn and another in late afternoon, with shorter, less regular, and more casual periods during mid-day and at night (Arnold and Dudzinski, 1978). Cattle peak grazing activities are between the hours of 6 to 9 am and then again from 6 to 11.30 pm (Popp, 1995).

Grazing sheep and cattle prefer a mixed diet to single diet (Soder et al., 2009), showing a partial preference for certain functional groups of plants such as legumes (Parsons et al., 1994). Several explanations as to why livestock select mixed diets include, (i) maintenance of a diverse rumen microflora (Rutter et al., 2000); (ii) maintenance of some optimal C-N balance (Senft et al., 1987; Soder et al., 2009); (iii) avoidance of toxic consequences of ingestion of one dietary component to excess (Provenza et al., 1992); (iv) constant sampling and evaluation of familiar foods in familiar environments, as nutrient content and toxicity may vary with time (Provenza et al., 1992). The diet eaten by grazing animals usually contain higher proportion of leaf and live plants and lower proportions of stem and dead tissue (Soder et al., 2009). Also, an animal grazing on a mixed sward frequently tends to graze some plant species more than others.

There is a close relationship between the feed intake and performance of grazing animals (Hodgson, 1990). Thus, variations in sward conditions are likely to influence herbage intake and animal performance. These variations in the observed animal performance can be explained by herbage measurements such as biomass yield and quality. It is therefore important to measure the performance of grazing animals in binary grass-legume mixtures to determine which mixture have greater influence on the animals (Soder et al., 2009).

Change in the live weight (LW) of the grazing animal is the most common and informative measure of animal performance. This variable has both health and economic importance; as weight change of animals may be used as an indication of health status and marketing, respectively (Coates and Penning, 2000). However, the live weight can vary over short periods of time and is dependent upon factors such as gut fill, which account for 20% of LW and changes in body water volume (Coates and Penning, 2000). These variations can be limited by using shrink body weights (no feed or water for 12 hours before weighing) or weighing animals on two consecutive days at the same time each day (Cook and Stubbendieck 1986; Coates and Penning, 2000). The amount and rate of shrink that animals experience are affected by age and productive status of the animals, forage and environmental conditions (Heitschmidt, 1982). For example, lactating cows shrink more than dry cows and calves weighing less than 50 kg experience no significant shrink or fill when left with their dam. However, as they increase in age and weight, their rate of shrink or fills increases (Heitschmidt, 1982; Cook and Stubbendieck 1986; Coates and Penning, 2000). In the absence of shrink, grazing animals follow a diurnal pattern of weight loss and gain. Lactating cows weighed 11 kg more at mid-morning than they did at 7:00-7:30 am (Heitschmidt, 1982). The researcher also found a linear regression analysis which indicated that the rate of weight loss was approximately 1% every 3 hrs after an initial 3 hr loss of 3.5% at fasted matured cows (Heitschmidt, 1982).

A limitation to this technique is the inability to determine the chemical composition of live-weight gain and changes that occur in the chemical composition of the entire animal (Coates and Penning, 2000). Corbett (1978), stated there may be as much as a three-fold variation in energy value between unit gain made at low BW by young, lean animals and unit gain of heavy, fat animals.

In addition to the changes in live weight, grazing animal performance can be measured by changes in body composition through use of body condition scoring or ultrasound techniques (Coates and Penning, 2000). Body condition scoring is a simple, cost-effective but subjective technique used to estimate body composition of animals (Coates and Penning, 2000). Scoring can also be used to assess the general nutritional status of the animal when adequate standards are established. The assessor rates the animal between condition score 1 (very thin) to 5 (very fat) according to the description for each score (Gamage, 2014). The body condition scoring or ultrasound techniques is based on relationships between physical measurements of areas such as the thickness of fat over the eye muscle at the eleventh rib or the rib-eye area as an indicator of muscling (Ward, 2009). The ultrasound measure can be used for both live or carcass animals.

This technique involves ultrasound imaging to determine subcutaneous fat depth and eye muscle areas as indices of carcass composition (Coates and Penning, 2000).

2.12 References

Aasen, A and Bjorge, M. 2009. Alberta forage manual. Alberta Agriculture and Rural Development. Edmonton, Alberta.

Acharya, S.N. 2009. Veldt cicer milkvetch. Can. J. Plant Sci. 89:511–513. http://doi.org/10.4141/CJPS08155

Acharya, S.N. 2015. AAC Mountainview sainfoin (*Onobrychis viciifoila* subsp. *Viciifolia*). Can. J. Plant Sci. 95(3): 603–607. http://doi.org/10.4141/cjps-2014-332

Acharya, S.N. 2001. AC Oxley II cicer milkvetch. Can. J. Plant Sci. 81: 749–751

Acharya, S., Sottie, E., Coulman, B., Iwaasa, A., Mcallister, T., Wang, Y., and Liu, J. 2013. New sainfoin populations for bloat-free alfalfa pasture mixtures in western Canada. Crop Sci. 53(5): 2283–2293. http://doi.org/10.2135/cropsci2012.10.0591

Adams, D.C. 1987. Influence of Winter Weather on Range Livestock. In "Proceedings, Grazing Livestock Nutrition Conference, July 23-24, 1987, Jackson, Wyoming." Univ. Wyo., Laramie, Wyo., pp. *23-29.*

Adesogan, A.T., Givens, D.I. and Owen, E. 2000. Measuring chemical composition and nutritive value of forages. Pages 263-278 in Field and laboratory methods for grassland and animal production research. L. t'Mannetje and R. M. Jones (eds.). CAB International, Wallingford, UK.

Agriculture and Agri-Food Canada. 2001. Forage. Bi-weekly Bulletin vol. 14 no. 7.

Akhter, S., Owen, E., Theodorou, M. K., Butler, E. A. and Minson, D. J. 1999. Bovine faeces as a source of microorganisms for the in vitro digestibility assay of forages. Grass Forage Sci.

Allden, W.G. and Whittaker, I.A.M. 1970. The determination of herbage intake by sheep: The interrelationship of factors influencing herbage intake and availability. Aust. J. Agr. Res. 21:755–766.

Allen, M.S. 1996. Physical Constraints on Voluntary Intake of Forages by Ruminants. J. Anim. Sci. 74: 3063–3075.

Allison, C.D. 1985. Factors Affecting Forage Intake by Range Ruminants: A Review. J. Range Mgt. 38(4):305–311.

Arnold, G.W. and Dudzinski, M.L. 1978. "Ethnology of Free Ranging Domestic Animals." Elsevier, N.Y. 198 pp.

Baldridge, D.E. and Lohmiller, R.G.E. 1990. Montana interagency plant materials handbook. Montana State University, Bozeman, MT.

Barnes, R.F., Nelson, C.J., Moore, K.J., and Collins, M. 2003. Forages: the science of grassland agriculture. Vol. II, 6th ed. Blackwell Publishing, Ames, IA, USA.

Bates, E.G. 1993. The effect of grazing pressure on animal performance, diet characteristics, and plant persistence of alfalfa. Ph.D Thesis. University of Georgia, Athens, Georgia

Beran, D.D., Masters, R.A. and Gaussoin, R.E. 1999. Grassland establishment with imazethapyr and imazapic. Agron. J. 91:592–596.

Berdahl, J.D., Wilton, A.C. and Frank, A.B. 1989. Survival and agronomic performance of 25 alfalfa cultivars and strains interseeded into rangeland. J. Range Manage. 42: 312–316.

Bittman, S. and McCartney, D.H. 1994. Evaluating alfalfa cultivars and germplasms for pastures using the mob-grazing technique. Can. J. Plant Sci. 74:109–114.

Bonnet, O., Hagenah, N., Hebbelmann, L., Meuret, M., Shrader, A. 2011. Is hand-plucking an accurate method of estimating bite mass and instantaneous intake rate of grazing herbivores? Rangeland Ecology and Management, 64:366–374.

Burns, J.C., Pond, K.R. and Fisher, D.S. 1994. Measurement of forage intake. In Forage quality, evaluation, and utilization. G. C. Fahey, ed. ASA, CSSA, SSSA. Madison, WI.

Burris, R., Randolph, J., Gay, N., Rasnake, M. and Lacefield, G. 1993. Rotational grazing of alfalfa with yearling cattle– 3 years. Univ. of Kentucky Beef Cattle Res. Rep, Lexington.

Caldwell, M.M. 1984. Plant Requirements for Prudent Grazing. In Natl. Res. Council/Natl. Acad. Sci. "Developing Strategies for Rangeland Management." Westview Press, Boulder, CO.

Coates, D.B. and Penning, P. 2000. Measuring animal performance. (353-402) in 't Mannetje, L. and Jones, R. M. (eds). Field and laboratory methods of grassland and animal production research. CABI Publishing, Wallingford, UK.

Collins, M. and Fritz, J.O. 2003. Forage Quality Pages 363-390 in Forages: An Introduction to Grassland Agriculture, 6th ed. Vol. 1. R. F. Barnes, C. J. Nelson, M. Collins and K. J. Moore (eds.). Iowa State Press, Ames, Iowa.

Cook, W.C. and Stubbendieck, J. 1986. Range Research: Basic problems and techniques. Society for Range Manegment. Denver, Colorado.

Corbett, J.L. 1978. Measuring animal performance. In: t' Mannetje, L. (ed.) Measurement of Grassland vegetation and Animal production. Bulletin 52 Commonwealth Bureau of Pasture and Field Crops.CAB, Farnham Royal, UK, pp.

Cordova, E.J., Wallace, J.D. and Pieper, R.D. 1978. Forage Intake by Grazing Animals: A Review. J. Range. Mgt. 31(6): 430–438.

Costigan, P. and Ellis, K.J. 1988. Analysis of fecal chromium derived from controlled release marker devices. N.Z.J. Technol. 3: 89–92.

Coulman, B.E. and Knowles, R.P. 1995. Hybrids between smooth and meadow bromegrass. In Eastern Forage Improvement Conference. Ottawa, ON. (p. 49–50.).

Coulman, B. 1998. Agronomic practices for hybrids of smooth x meadow bromegrass. Agriculture and Agri-Food Canada. Internal Report.

Coulman, B. 2004. Knowles hybrid bromegrass. Can. J. Plant Sci. 84: 815–817.

Coulman, B. 2006. Success hybrid bromegrass. Can. J. Plant Sci. 86:745–747.

Coulman, B. 2009. AC Admiral Meadow Bromegrass. Technical Bulletin.

Crosbie, S.F., Smallfield, B.M., Hawker, H., Floate, M.J.S., Keoghan, J.M., Enright P.D. and Abernethy, R.J. 1987. Exploiting the pasture capacitance probe in agricultural research. J. Agric. Sci. 108:155–163.

Daubenmire, R. 1959. A Canopy-coverage method of vegetational analysis. Northwest Science, 33:43–64.

Demment, M.W., and Van Soest, P.J. 1983. "Body Size, Digestive Capacity, and Feeding Strategies of Herbivores." Winrock International, Morrilton, Ark.

Dhakal, D. 2015. Forage Grass-legume Mixture for Improved Forage Yield, Forage Quality, Stand Persistence, Soil Properties, and Economics. Ph.D. Thesis Department of Plant Sciences, University of Wyoming, Laramie, Wyoming.

Dougherty, C.T. 1991. Influence of Ingestive Behavior on Nutrient Intake of Grazing Livestock. Okla. Agric. Expt. Sta. Misc. Pub. MP-133.

Douglas, J.T. and Crawford, C.E. 1994. An evaluation of the drop-disc technique for measurements of herbage production in ryegrass for silage. Grass Forage Sci. 49: 252–255.

Dubach, M. and Russelle, M.P. 1994. Forage legume roots and nodules and their role in nitrogen transfer. Agron. J. 86: 259–266.

Earle, D.F. and McGowan, A.A. 1979. Evaluation and calibration of an automated rising plate meter for estimating dry matter yield of pasture. Aust. J. Exp. Agric. Anim. Husb. 19: 337–343.

Edlefsen, J.L., Cook, C.W., and Blake, J.T. 1960. Nutrient content as determined by hand-plucked and esophageal fistula samples. J. Anim. Sci. 19: 560-567

Ferdinandez, Y.S.N. and Coulman, B.E. 2001. Nutritive values of smooth bromegrass, meadow bromegrass, and meadow x smooth bromegrass hybrids for different plant parts and growth stages. Crop Sci. 41(2): 473–478. http://doi.org/10.2135/cropsci2001.412473x

Forbes, J.M. 1986. "The Voluntary Food Intake of Farm Animals." Butterworth & Co., London, Eng.

Forbes, J.M. 2007. Voluntary food intake and diet selection in farm animals second edition. CABI. Wallingford, UK.

Frame, J. 2005. Forage Legumes for Temperate Grasslands. Enfield, NH, USA.: FAO. Science Publishers, Inc.

Fraser, M.D.,Speijers, M.H.M.,Theobald, V.J., Fychan, R., and Jones, R. 2004. Production performance and meat quality of grazing lambs finished on red clover, lucerne or perennial ryegrass swards. Grass Forage Sci. 59:345–356.

Freer, M. 1981. The Control of Food Intake by Grazing Animals. In Morley, F. H. W. (Ed.), "Grazing Animals." Elsevier Sci. Pub. Co., Amsterdam, Neth.

Fuller, L. 2010. Chernozemic soils of the prairie region of Western Canada. Prairie Soils and Crops J. 3: 37–45.

Gamage, R.S.K.D. 2014. Utilization of Stockpiled Perennial Forages in Winter Feeding Systems for Beef Cattle. Msc thesis. University of Saskatchewan, Saskatoon, SK

Goplen, B.P., Richards, K.W. and Moyer, J.R. 1991. Sainfoin for western Canada. Agriculture Canada Publi. 1470/E , Ottawa, Ont.

Grovum, W.L. 1987. A New Look at What Is Controlling Food Intake. Okla. Agric. Expt. Sta. Misc. Pub. 121,.

Guyader, J., Janzen, H.H., Kroebel, R. and Beauchemin, K. 2016. Forage use to improve environmental sustainability of ruminant production. J. Anim. Sci. 94*:* 3147–3158.

Hakkila, M. D., Holechek, J. L. Wallace, J. D., Anderson, D. M. and Cardenas, M. 1987. Diet and Forage Intake of Cattle on Desert Grassland Range. J. Range Mgt., 40(4): 339–342.

Hanna, R.R. 1981. Registration of Nova sainfoin. Crop Science 21: 987.

Hanson, C.L., Morris, R.P. and Wight, J.R. 1983. Using Precipitation to Predict Range Herbage Production in Southwestern Idaho. J. Range Mgt., 36(6):766–770.

Heitschmidt, R.K. 1982. Diurnal variation in weight and rates of shrink of range cows and calves. J. Range Manage. 35: 717–720.

Hendrickson, J.R. and Berdahl, J.D. 2003. Survival of 16 alfalfa populations, space planted into a grassland. J. Range. Manage. 56:260–265.

Hendrickson, J.R., Liebig, M.A. and Berdahl, J.D. 2008. Responses of *Medicago sativa* and *M* falcata type alfalfas to different defoliation times and grass competition. Can. J. Plant Sci. 88(1) :61–69.

Hilty, J. 2007. Prairie Wildflowers of Illinois. http://www.illinoiswildflowers.info/prairie/plant_index.htm#purple_clover. Accessed 18 July 2007.

Hodgson, J. 1990. "Grazing Management: Science into Practice." John Wiley & Sons, New York.

Hudson, R.J. and Frank, S. 1987. Foraging ecology of bison in aspen boreal habitats. J. of Range Mgt. 40:71–75.

Hunter, R.A. 1991. Strategic Supplementation for Survival, Reproduction, and Growth of Cattle. Okla. Agric. Expt. Sta. Misc. Pub. MP-133.

Hybner, R.M. 2013. Sainfoin *(Onobrychis viciifolia* Scop.*)* An Introduced Legume for Conservation Use in Montana and Wyoming. United States Department of Agriculture-Natural Resources Conservation Service, Plant Materials Technical Note No. MT-91.

Jefferies, N.W. and Rice, R. 1969. Nutritive value of clipped and grazed rage forage samples. J. Range. Manage. 2(3):192–195.

Jefferson, P.G., Lawrence, T., Irvine, B.R. and Kielly, G.A. 1994. Evaluation of sainfoin-alfalfa mixturcs for forage prcduction and compatibility at a semi-arid site in southern Saskatchewan. Can. J. Plant Sci. 74: 785–791.

Jensen, N. and USDA NRCS. (2002). Canadian Milkvetch *(Astagalus canadensis* L.*)* http://plants.usda.gov/factsheet/pdf/fs_asca11.pdf. Accessed 28 January 2008.

Judy, J.V. 2014. Effects of stocking rate on forage nutrient composition of Nebraska sandhills upland range when grazed in early summer and the effects of grazing on Nebraska sandhills meadow forage nutrient composition. Msc. Thesis. Department of Animal Science. University of Nebraska, Lincoln, Nebraska

Klingman, D.L., Miles, S. R. and Mott, G.O. 1943. The cage method for determining consumption and yield of pasture herbage. J. Am. Soc. Agron. 35: 739–746.

Knowles R., Baron, V. and McCartney, D. 1993. Meadow Brome grass. Agriculture Canada Publication 1889/E. Communications Branch, Agriculture Canada, Ottawa, Ont.

Krall, J.M. 1979. N_2 (C_2H_2) fixation patterns in Sainfoin (*Onobrychis viciifolia* Scop.) and alfalfa (*Medicago sativa* L.) grown in six soils. PhD Thesis. University of Wyoming.

Krysl, L.J., Galyean, M.L. Wallace, J.D. McCollum, F.T. Judkins, M.B. Branine, M.E. and Caton, J.S. 1987. Cattle Nutrition on Blue Grama Rangeland in New Mexico. N. Mex. Agric. Expt. Sta. Bul. 727.

Kusler, J. 2009. Comparing simple and complex native forage mixtures in southern Saskatchewan. MSc Thesis.Department of Animal and Poultry Science. University of Saskatchewan, Saskatoon, SK. University of Saskatchewan, Saskatoon, SK

Lawrence, T. and Heinrichs, D.H. 1977. Growing Russian wild ryegrass in western Canada. Agriculture Canada. Pub. 1607.

Li, Y., Iwaasa, A.D., Wang, Y., Jin, L., Han, G. and Zhao, M. 2014. Condensed tannins concentration of selected prairie legume forages as affected by phenological stages during two consecutive growth seasons in western Canada. Can. J. Plant Sci. 94(5): 817–826. http://doi.org/10.4141/cjps2013-234

Li, Y.G., Tanner, G. and Larkin, P. 1996. The DMACA-HCl protocol and the threshold proanthocyanidin content for bloat safety in forage legumes. J. Sci. Food Agric.70: 89–101.

Lissbrant, S., Stratton, S., Cunningham, S.M., Brouder, S.M. and Volenec, J.J. 2009. Impact of long-term phosphorus and potassium fertilization on alfalfa nutritive value–yield relationships. Crop Sci. 49: 1116–1124.

Loeppky, H.A., Bittman, S., Hiltz, M.R. and Frick, B. 1996. Seasonal changes in yield and nutritional quality of cicer milkvetch and alfalfa in northeastern Saskatchewan. Can. J. Plant Sci. 76:441–446.

Luscher, A.I., Mueller-Harvey, I., Soussana, J.F., Rees, R.M and Peyraud, J. 2014. Potential of legume-based grassland–livestock systems in Europe: a review. Grass and Forage Science, 69: 206–228.

Marten, G.C., Ehle, F.R. and Ristau, E.A. 1987. Performance and photosensitization of cattle related to forage quality of four legumes. Crop Sci. 27: 138–145.

Marten, G.C., Jordan, R.M. and Ristau, E.A. 1990. Performance and adverse response of sheep during grazing of four legumes. Crop Science. 30: 860–866.

Matejovsky, K.M., and Sanson, D.W. 1995. Intake and digestion of low, medium and high-quality grass hays by lambs receiving increasing levels of corm supplementation. J Anim. Sci. 73: 2156–2163.

McCartney, D. and Horton, P.R. 1997. Canada's Forage Resources (pp. 1–10). Winnipeg. MB: Proceedings XVII International Grassland Congress.

McGeough, E.J., Cattani, D.J., Koscielny, Z., Hewitt, B and Ominski, K.H. 2018. Annual and perennial forages for fall/winter grazing in western Canada. Can J. Plant Sci. 98(2): 247–254.

McGraw, R.L., Shockley, F.W. Thompson, J.F. and Roberts, C.A. 2004. Evaluation of native legume species for forage yield, quality, and seed production. Native Plants. Fall 2004.

Mcleod, J.G., Jefferson, P.G., Muri, R. and Lawrence, T. 2003. Tom Russian wildrye. Can. J. Plant Sci. 83:789–791.

Mcleod, J.G., Muri, R., Jefferson, P.G., Bittman, S. and Mccartney, D. 2009. Yellowhead alfalfa. Can. J. Plant Sci. 89: 653–655.

Mendoza, R., García, I., Depalma, D. and López, C. 2016. Competition and growth of a grass–legume mixture fertilised with nitrogen and phosphorus: effect on nutrient acquisition, root morphology and symbiosis with soil microorganisms. Crop and Pasture Sci. 67: 629–640.

Meuret, M., Lécrivain, E. and Leclerc, B. 1986. Foraging behaviour of goats herded within a Mediterranean live oak coppice. [In French]. Reproduction, Nutrition, Development, 26: 265–266.

Minson, D.J. and McDonald, C.K. 1987. Estimating forage intake from the growth of beef cattle. Trop. Grassl. 21: 116–122.

Minson, D.J. 1990. "Forage in Ruminant Nutrition." Academic Press, San Diego, CA.

Mortenson, M.C., Schuman, G.E., Ingram, L.J., Nayigihugu, V. and Hess, B.W. 2005. Forage production and quality of a mixed-grass rangeland interseeded with *Medicago sativa* spp. falcata. Rangeland Ecol. Manage., 58(5):505–513.

Mortenson, M.C., Schuman, G.E. and Ingram, L.J. 2004. Carbon sequestration in rangelands interseeded with yellowflowering alfalfa (*Medicago sativa* spp. falcata). Envrin. Manage., 33 (Suppl., S475–S481.

Mowrey, D.P., Matches, A.G. and Preston, R.L. 1992. Utilization of sainfoin by grazing steers and a method for predicting daily gain from small-plot grazing data. J. Anim. Sci. 70: 2262–2266.

Newman, J.A., Parsons, A. J. Thornley, J.H.M., Penning, P.D. and Krebs, J.R. 1995. Optimal diet selection by a generalist grazing herbivore. Functional Ecology 9: 255–268.

NRC. 1987. "Predicting Feed Intake of Food-Producing Animals." Natl. Academy Press, Washington, D.C.

NRC. 1996. Nutrient requirements of beef cattle. 7th revised edition. Washington, D. C., National Academy Press.

Ogle, D., John, L.S., Holzworth, L.K., Jensen, K. B. and USDA NRSC. 2006. Meadow Brome *Bromus biebersteinii Roem. & Schult.* http://plants.usda.gov/plantguide/pdf/pg_brbi2.pdf. Accessed 28 January 2008.

Ogle, D., St. John, L., Cornwell, J., Holzworth, L., Majerus, M., Tober D., Jensen, K., Sanders, K.E. (rev) St. John. 2012a. Plant Guide for Russian Wildrye *(Psathyrostachys junceus).* USDA-Natural Resources Conservation Service, Aberdeen Plant Materials.

Ogle, D., St. John, L., Holzworth, L., Jensen, K. and Tilley, D. Ed. (rev) St. John. 2012b. Plant Guide for Meadow Brome (*Bromus biebersteinii*). USDA-Natural Resources Conservation Service, Aberdeen Plant Materials Centre. Aberdeen, Idaho 83210.

Parsons, A.J., and Johnson, I.R. 1986. The Physiology of Grass Growth Under Grazing. In J. Frame (Ed.). "Grazing." British Grassland Soc., Hurley, Berks, Eng.

Parsons, A.J., Newman, J.A., Penning, P.D., Harvey, A., Orr, R.J. 1994. Diet preference of sheep: effects of recent diet, physiological state and species abundance. J. Anim. Ecol. 63: 465–478.

Pearson, H.A. 1975. Herbage Disappearance and Grazing Capacity Determinations of southern Pine Bluestem Range. J. Range Mgt. 28(1): 71–73.

Penning, P. D. and Hooper, G.E. 1985. An evaluation of the use of short-term weight changes in grazing sheep for estimating herbage intake. Grass Forage Sci. 40: 79–84.

Popp, J.D, McCaughey, W.P, Thomas, L.R and Cohen, R.D. 1999. Nutrient selection by cattle from grass and grass/legume pastures. Can J. Anim. Sci. 79: 391–395.

Popp, J.D., McCaughey, W.P. and Cohen, R.D.H. 1997. Grazing system and stocking rate effects on the productivity, botanical composition and soil surface characteristics of alfalfa-grass pastures. Can. J. Anim. Sci. 77:669–676.

Popp, J.D., McCaughey, W.P. Cohen, R.D.H. McAllister, T.A. and Majak, W. 2000. Enhancing pasture productivity with alfalfa: A review. Can. J. Plant Sci. 80: 513–519.

Popp J.D. 1995. Beef production of alfalfa-grass pasture. PhD Thesis. University of Saskatchewan, Saskatoon, SK

Posler, G.L., Lenssen, A.W. and Fine, G.L. 1993. Forage yield, quality, compatability, and persistence of warm season grass-legume mixtures. Agron. J. 85: 554–560.

Provenza, F.D., Pfister, J.A. and Cheney, C. 1992. Mechanisms of learning in diet selection with reference to phytotoxicosis in herbivores. J. Range Mgt. 45: 36–45.

Quinn, J.A., and Hervey, D.E. 1970. Trampling Losses and Travel by Cattle on Sandhills Range. J. Range Mgt. 23(1): 50–55.

Rehemuti, M. 2014. Effect of Forage Legumes in Short-Term Rotation on Phosphorus Fertility of Four Saskatchewan Soils. Master's thesis, University of Saskatchewan, Saskatoon, SK

Richards, J.H., Caldwell, M.M. and Olson, B.E. 1987. Plant Production Following Grazing: Carbohydrates, Meristems, and Tiller Survival Over Winter. In D. A. Jameson and J. Holechek (Eds.), "Monitoring Animal Performance and Production Symposium Proceedings, February 12, 1987, Boise, Idaho." Society for Rang.

Rutter, S.M., Orr, R.J. and Rook, A. J. 2000. Dietary preference for grass and white clover in sheep and cattle: an overview. In: Rook, J.A and Penning, P.D. (Eds.). Grazing management: the principles and practice of grazing, for profit and environmental gain, within temperate grassland systems. Occa.

Rutter, S. 2006. Diet preference for grass and legumes in free-ranging domestic sheep and cattle: Current theory and future application. Applied Animal Behaviour Sci. 97:17–35.

Ruyle, G.B., and Rice, R.W. 1996. Aspects of Forage Availability and Short-Term Intake Influencing Range Livestock Production. Proc. Grazing Livestock Nutr. Conf. 3: 40–50.

Saskatchewan Forage Council. 2007. Forage factsheet. Dryland Forage Species Adaptation CD.

Sedivec, K., Tober, D., Duckwitz, W., Dewald, D., Printz, J. 2007. Grasses for the Northern Plains. Volume 1 Cool Season. North Dakota State University Extension, Fargo, ND.

Senft, R.L., Stillwell, M.A. and Rittenhouse, L.R. 1987. Nitrogen and energy budgets of free-roaming cattle. J. Range Mgt. 40: 421–424.

Sneva, E.A. 1977. Correlations of precipitation and temperature with spring. regrowth, and mature crested wheatgrass yields. J. Range Mgt. 30(4): 270–275.

Soder, K.J., Gregorini, P., Scaglia, G. and Rook, A.J. 2009. Dietary selection by domestic grazing ruminants in temperate pastures: current state of knowledge, methodologies, and future direction. Rangeland Ecol Mgt. 62: 389–398.

Sottie, E.T., Acharya, S.N., McAllister, T., Thomas, J., Wang, Y. and Iwaasa, A. 2014. Alfalfa pasture bloat can be eliminated by intermixing with newly-developed sainfoin population. Agronomy J. 106 (4): 1470–1478. http://doi.org/10.2134/agronj13.0378

Sottie, E.T. 2014. Characterization of new sainfoin populations for mixed alfalfa pastures in western Canada. PhD Thesis. University of Lethbridge, Lethbridge, AB

Spedding, C.R.W and Diekmahns, E.C. 1972. Grasses and legumes in British Agriculture.

Bulletin No. 49. Commonwealth Bureau of Pastures and Field Crops, Farnham Royal.

Statistics Canada. 2011. Census of agriculture, farm and farm operator data. Catalogue no. 95-640-XWE.

Statistics Canada. 2012. Agriculture Statistics. Statistics Canada, Ottawa.

Stubbendieck, J.L and Conard, E.C. 1989. Common legumes of the Great Plains: An Illustrated Guide. University of Nebraska Press. Lincoln, NE.

t' Mannetje, L. 1978. Measuring quantity of grassland vegetation. Pages 63-95 in 't Mannetje ed. Measurement of grassland vegetation and animal production. CAB, Farnham Royal, Bucks, England.

Thompson, L. 2003. Forage production and performance of beef yearling graziing hybrid bromegrass. MSc. Thesis. Dept. of Animal and Poultry Science. University of Saskatchewan, Saskatoon, SK.

Thonney, M.L., Duhaime, D.J., Moe, P.W. and Reid, J.T. 1979. Acid insoluble ash and permanganate lignin as indicators to determine digestibility of cattle rations. J. Anim. Sci. 49: 1112–1116.

Tilley, D., Ogle, D. and St. John, L. 2008. Sainfoin, plant guide. United States Department of Agriculture/ Natural Resources Conservation Service. pp 1-4. Available online: http://www.nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/publications/idpmcpg7792.pdf. Accessed: October 18, 2013.

Undi, M., Wilson, C., Ominski, K.H. and Wittenberg, K.M. 2008. Comparison of techniques for estimation of forage dry matter intake by grazing beef cattle. Can. J. Anim. Sci. 88: 693–701.

USDI Bureau of Land Management. 1985. Rangeland monitoring - Trend Studies TR4400-4.

Vallentine, J.F. 2001. Grazing Management. 2nd edition. Academic Press.San Diego, CA. Retrieved from http://www.sciencedirect.com/science/article/B83X7-4MSSPMB-S/2/05b99c4e7ed635ec474f319de08a4480

Van Soest, P.J. 1994. Nutritional Ecology of the Ruminant. 2nd edn., Cornell University Press, Ithaca, New York.

Wachendorf, M., Ingwersen, B. and Tube, F. 1999. Prediction of the clover content of red clover and whiten clover-grass mixtures by near-infrared reflectance spectroscopy. Grass Forage Sci., 54: 87–90.

Wallace, J.D., Hyder, D.N. and Van Dyne, G.M. 1972. Salivary contamination of forage selected by esophageal fistulated steers grazing sandhill grassland. J. Range Mgt. 25: 184–188.

Wallace, J.D. 1984. Some Comments and Questions on Animal Preferences, Ecological Efficiencies, and Forage Intake. In Natl. Res. Council/Natl. Acad. Sci. "'Developing Strategies for Rangeland Mangement." Westview Press, Boulder, CO.

Waller, S.S., Reece, E E. Moser, L. E. and Gates, G.A. 1985. “Understanding Grass Growth: The Key to Profitable Livestock Production.” Trabon Pnnt. Co., Kansas City, Mo.

Walton, P.D. 1983. The production and management of cultivated forages.Reston Publishing Company, Inc. Reston, Virginia.

Ward, C.I. 2009. The effect of perennial grass species on forage growth and quality, etiolated growth, animal performance and economics. MSc Thesis. University of Saskatchewan, Saskatoon, SK.

Whally, R.D.B. and Hardy, M.B. 2000. Mesuring botanical composition of grasslands.in t'Mannetje, L. and Jones, R. M. (eds). Field and laboratory methods of grassland and animal production research. CABI Publishing, Wallingford, UK.

Willis de Vries, M. 1995. Estimating forage intake and quality in grazing cattle: a reconsideration of the hand-plucking method. J. Range Mgt. 48: 370–375.

Wynia, R. 2008a. Plant Guide for purple prairie clover (*Dalea purpurea* Vent.) USDA-Natural Resources Conservation Service, Manhattan Plant Materials Centre, Manhattan, KS 66502. [Online]. Available: http://plants.usda.gov/plantguide/pdf/pg_dapu5.pdf. [2008 March 8].

Wynia, R. 2008b. Plant Guide for white prairie clover (*Dalea candida* Michx. ex Willd.) USDA-Natural Resources Conservation Service, Manhattan Plant Materials Centre, Manhattan, KS 66502.

Yarrow, N.H. and Penning, P.D. 2001. The liveweight gain of Limousin x Friesian heifers grazing perennial ryegrass-white clover swards of different clover content and the effects of their grazing on sward botanical composition. Grass Forage Sci. 56: 238–248.

3 Effect of Harvest Date on Biomass Yield, Botanical Composition and Quality of Binary Legume-Grass Mixtures

3.1 Introduction

Nitrogen (N) plays a key role in forage production and enables producers to achieve good yield for high economic returns. However, N fertilizers are not only costly but can be harmful to human health and the environment due to pollution and high nitrate concentrations (Nyfeler et al., 2009; Ribaudo et al., 2012), which accumulate on the leaves of forages, particularly if excessive N fertilizer is applied. Cuomo et al. (2005), reported that the cost of forage production for grass monoculture with N fertilization was 50% more compared to grass-legume mixture. Several studies have proposed that an alternative source of N that has potential to minimize input costs and environmental impact is the addition of legumes into pasture systems.

Generally, the use of legumes in pastures increases forage yield and quality of pastures in two ways: (i) fixing N that can then be used by companion grass species and (ii) directly contributing to overall forage production in the pasture. Studies by Nyfeler et al. (2011) and Dhakal (2015), have reported that legumes fix more atmospheric N when grown in a mixture with grass compared to a legume monoculture. This is because grass outcompetes the legume, to uptake available soil N and creates a micro-environment for legumes to fix more atmospheric N (Hogh-Jensen and Schjoerring, 1997).

In the summer (late July to early September) when temperatures are hottest, a ‘summer slump’ or period of reduced growth or grass dormancy is exhibited. Forage legumes compensate for the ‘summer slump’ of cool-season grasses during this period and can improve the seasonal distribution of pasture forage, thereby increasing the number of livestock that can by supported (Sleugh et al., 2000; Cox, 2013).

Sainfoin (*Onobrychis viciifolia* Scop.), cicer milkvetch (*Astragalus cicer* L.), purple prairie clover (*Dalea purpurea* Vent.), white prairie clover (*D. candida* Michx. Ex Willd) and Canadian milkvetch (*Astragalus canadensis* L.) are non-bloating (Li et al., 1996; Berard et al., 2011), and these forages could have the potential to improve livestock health and grazing performance. Sainfoin (cv. Nova) yielded 7, 17 and 56% greater forages than Melrose, Eski and Remont over 20 station-yrs at 9 locations in western Canada (Goplen et al., 1991). Sainfoin (cv. Mountainview) produced biomass yield 7 and 18% greater than Nova at AAFC SCRDC (rainfed) and Lethbridge, Alberta under irrigation, respectively (Acharya, 2015).

According to Iwaasa et al. (2012), both purple prairie clover and white prairie clover have seasonal growth characteristics and nutritional qualities that could be used to extend the grazing season and improve pasture biodiversity. Alfalfa (*Medicago sativa* L.) is an exceptional forage legume because of its high biomass yield and nutritive value for livestock performance. Alfalfa (cv. Yellowhead) produces yield not significantly different from check cultivar Barriers, Rambler, Rangelander, Henrichs and Beaver in a single harvest (McLeod et al., 2009). However, alfalfa causes bloat when grazed by livestock at early stages of growth.

Hybrid brome grass (*Bromus riparius* Rehm x *Bromus inermis* Leyss) is a dual-purpose forage for both hay and pasture systems (Aasen and Bjorge, 2009). The yield and quality of this grass species has shown potential for use in beef production system (Ferdinandez and Coulman, 2001) in the Canadian prairies. Hybrid bromegrass (cv. Success) produced biomass yield of 9 and 11% greater than Carlton smooth bromegrass and Fleet meadow bromegrass, respectively, in the Brown soil zone in Saskatchewan (Coulman, 2006). The author found that Success hybrid bromegrass has similar CP to Carlton smooth bromegrass, and 18 and 15% greater CP than Fleet meadow bromegrass. Russian wildrye (*Psathyrostachys junceus* [Fisch.] Nevski) is an excellent species palatable to all classes of livestock and retains higher protein content than most grasses after maturity (Ogle et al., 2012b). Russian wildrye (Tom) yielded 13 and 14% and 8 and 18% more forages than Swift and Tetracan harvested as hay and pastures, respectively at AAFC Saskatoon.

Meadow bromegrass (*Bromus riparius* Rehm.) is highly palatable to all classes of livestock and wildlife (Sedivec et al., 2007; Ogle et al., 2012b) and has excellent recovery under intensive rotational grazing (Ogle et al., 2006). Meadow bromegrass (cv. Admiral) produced 1% greater yield than Fleet in the western Forage Testing System Trials from 2005 to 2007.

Several studies by Sleugh et al. (2000), Nelson and Burns (2006) and Kim and Albrecht (2011), reported that grass-legume mixtures produce higher quality forage (crude protein [CP]) than N-fertilized grass production system. Higher quality forage was obtained from tall fescue (*Festuca arundinacea* L.) mixed with alfalfa and birdsfoot trefoil (*Lotus orniculatus* L.) than with N-fertilized grass monoculture (Lauriault et al., 2003). In addition, Albayrak et al. (2011), found higher total digestible nutrient (TDN) in forage from grass-alfalfa mixture than N fertilized grass monoculture. Russian wildrye-alfalfa mixture was reported to produce higher CP and DM digestibility than N-fertilized Russian wildrye monoculture (Schultz and Stubbendieck, 1982).

Beef producers in the prairies are becoming more interested in stockpiled forage because of its economic benefits due to reduced need for mechanical harvesting, less labor and manure management. However, according to Lardner et al. (2013), much of the previous research in this area has focused on stockpiling pure stand of perennial forage species except meadow brome mixed with alfalfa for stockpiling. The present small plot study tested the stockpiling of eight species (five legumes and three grasses) at Saskatoon (Dark brown soil ecoregion) and 12 species (nine legumes and 3 grasses) at Swift Current (Brown soil ecoregion).

The main objective for this experiment was to evaluate the effects of summer and fall harvests on biomass yield, grass and legume proportions, and quality of binary legume-grass pasture mixtures at two different ecoregions and soil zones in Saskatchewan.

3.2 Materials and Methods

3.2.1 Research Study Sites and Experimental Design

A 2-yr (2016 and 2017) study was conducted at two different sites; (i) Agriculture and Agri-Food Canada's Swift Current Research and Development Centre (SCRDC), (50°16′N 107°44′W), Saskatchewan, and (ii) Agriculture and Agri-Food Canada's Saskatoon Research Farm, (52°04′N, 108°08′W), Saskatchewan. The soil at AAFC SCRDC site is classified as Orthic Brown Chernozem, Swinton association of a silt-loam texture on a gently sloping topography (Saskatchewan Soil Survey, 1990), while soil at AAFC Saskatoon site is classified as an Orthic Dark Brown Chernozem, Shellbrook-Hamlin association on a nearly level topography of very fine sandy loam to loam texture (Saskatchewan Soil Survey, 1999).

Small plot study sites varied due to land availability and were 4740 m^2 (155.4 m x 30.5 m) at AAFC SCRDC and 702 m^2 (25.9 m x 27.1 m) at AAFC Saskatoon and consisted of four rows, spaced 30 cm apart. At AAFC Saskatoon, guard rows of Kirk crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) were planted on each side of the trial whereas as AAFC SCRDC, the trial was enclosed by a Deer fence (Deer Fence Canada Inc.) and the guard rows were creeping red fescue (*Festuca rubra* L. ssp. Arenaria (Osbeck) F. Aresch.). The experiment was conducted as randomized complete block design in a split-plot arrangement with four (n=4) replicates at either site (Appendix Figure A.3 and A.4). Each treatment was replicated (n=4) at either site. The main plot was binary mixtures (treatments) whereas the sub-plot was the harvest date.

3.2.2 Establishment of Binary Grass-Legume Pasture Mixtures

The number of binary mixtures (treatments) vary with sites; 15 treatments (eight species; five legumes and three grasses) at AAFC Saskatoon and 27 treatments (12 species; nine legumes and three grasses) at AAFC SCRDC. The treatment at AAFC Saskatoon and AAFC SCRDC sites are presented in Table 3.1 and 3.2, respectively.

At both study sites soil samples were taken in spring 2015 to determine soil N, Phosphorus (P), potassium (K) and sulphur (S) levels. Based on the soil test recommendations (Appendix Table A.1); no fertilizer was applied at AAFC SCRDC, however, 11:52:0 was applied at 38.4 kg ha^{-1} post-seeding (October 22, 2015) at AAFC Saskatoon. No herbicide application was applied at AAFC Saskatoon site. However, at AAFC SCRDC, on May 20, 2015, Roundup Transorb and Basagran® were applied at 2.5 and 2.2 liter per hectare, respectively.

Most of the forage binary mixture seeds were obtained from a commercial source (Crop Production Services, Inc. and now Nutrien Ag Solutions). However, the Success hybrid (HBG) and Admiral meadow bromegrass (MBG) were from AAFC Saskatoon Research and Development Centre, the Great Plains-Ecovar Canadian milkvetch (GCM) was from AAFC-Swift Current Research and Development Centre and the AC Lamour purple prairie clover (PPC) and AC Antelope white prairie clover (WPC) were from the NRCS Bismarck Plant Material

Centre. The sainfoin cultivars (AC Mountainview, Delaney, Shoshone and Nova) were seeded at 30 pure live seeds (PLS) m^{-1}, while the AC Yellowhead alfalfa (ALF), Great Plains-Ecovar Canadian milkvetch (GCM), AC Veldt cicer milkvetch (CMV), AC Lamour purple prairie clover (PPC), AC Antelope white prairie clover (WPC), AC Success hybrid bromegrass (HBG), Tom Russian wildrye (RWR), Admiral meadow bromegrass (MBG) was seeded at 50 PLS m^{-1} in a mixed-row at AAFC SCRDC (self-propelled hydrostatic plot seeder) (Swift Machine and Welding, Swift Current, Saskatchewan) on May 28, 2015 and in Saskatoon a "Hege" plot seeder was used on May 29, 2015. Seeding depth was 1.9 cm and spaced 30 cm apart at both AAFC SCRDC and AAFC Saskatoon.

Table 3.1. Tame Legume and Grass Binary Mixtures (Treatment) at AAFC Saskatoon

No.	Legumes	Grasses
1	AC Yellowhead alfalfa (ALF)	AC Success hybrid bromegrass (HBG)
2	AC Mountainview sainfoin (MSF)	Tom Russian wildrye (RWR)
3	AC Veldt cicer milkvetch (CMV)	AC Admiral meadow bromegrass (MBG)
4	Nova sainfoin (NSF)	
5	Shoshone sainfoin (SSF)	

Table 3.2. Tame and Native Legume and Grass Binary Mixtures (Treatment) at AAFC SCRDC

No.	Legumes	Grasses
1	AC Yellowhead alfalfa (ALF)	AC Success hybrid bromegrass (HBG)
2	AC Mountainview sainfoin (MSF)	Tom Russian wildrye (RWR)
3	AC Veldt cicer milkvetch (CMV)	AC Admiral meadow bromegrass (MBG)
4	Nova sainfoin (NSF)	
5	Shoshone sainfoin (SSF)	
6	Delaney sainfoin (DSF)	
7	AC Lamour purple prairie clover (PPC)	
8	Antelope white prairie clover (WPC)	
9	Great Plains Ecovar Canadian milkvetch (GCM)	

3.2.3 Forage Yield, Botanical Composition and Quality and Sampling

Forage DM yield was determined; (i) at AAFC SCRDC by mechanical harvest of a 0.6 x 5-m area with flail plot harvester (Swift Machine and Welding, Swift Current, Saskatchewan) in July and September for both yrs and (ii) at AAFC Saskatoon by clipping randomly placed two 0.25 m^2 quadrats to 2 cm stubble height within each replicated (n=4) plot in July in 2016 and July and September in 2017. The September harvest at AAFC Saskatoon in 2016 was done by a HALDRUP F-55 grass harvester. All harvested biomass was weighed fresh and a subsample collected for DM and further laboratory analysis.

Proportion of composition of each treatment plot was determined by clipping 1-m linear row length (middle row) within each plot (n=4) and then hand separated into grass and legume components. Each forage component was then placed in a forced air oven and dried at 60^{o}C for 48 h to a constant weight.

3.2.4 Laboratory Analysis

Prior to forage quality analyses, all dried samples were ground to pass through a 1-mm screen Wiley mill (Thomas-Wiley, Philadelphia, PA) and stored in either sealed plastic bags at AAFC Saskatoon or glass jars at AAFC SCRDC site. Forage quality analyses included crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), organic matter (OM), *in vitro* organic matter digestibility (IVOMD), acid detergent lignin (ADL), calcium (Ca) and P for the July and September harvested forages.

Sequential NDF and ADF were determined using an ANKOM^{200} fibre analyzer (Model 200; ANKOM; Fairport, NY). The ADL was determined using the procedure recommended by Klason technique (Van Soest, 1994). Total N concentration was determined using the micro-

Kjeldahl method (AOAC, 2012) and total N was multiplied by 6.25 to determine CP concentration. Calcium was determined using an atomic absorption spectrophotometer (PerkinElmer, Model 2380, CN, USA) while P concentration was read at 410 nm on a spectrometer (Pharmacia, LKB-Ultraspec® III, Stockholm, Sweden). The IVOMD was determined using the procedure established by Tilley and Terry (1963), and modified by (Troelsen and Hanel, 1966; Moore et al., 1972). Ash was determined by weighing a 1 g of sample into porcelain crucibles and heated at 600°C for 4 h (AOAC method 923.03; AOAC, 2005).

3.2.5 Statistical Analysis

Research data was subjected to analysis of variance (ANOVA) as a split plot with randomized complete block design (RCBD) using the SAS mixed model procedure (Version 9.3; SAS Inst., Inc., Cary, NC). The statistical model was:

$$Y_{ijk} = \mu + r_k + \alpha_\iota + w_{ik} + \beta_j + (\alpha\beta)_{ij} + e_{ijk}$$

where Yijk is the dependent variable, μ is the overall mean, rk is the k^{th} block effect (replicate),

α_ι is the effect of the i^{th} of the binary mixtures (whole plot factor)

w_{ik} is whole-plot error effect (=replicate x binary mixtures), β_j is the effect of the j^{th} of the harvest dates (sub plot factor).

$(\alpha\beta)_{ij}$ is the *ij*th binary mixtures x harvest dates interaction effect (main factor x subplot factor interaction*)*.

e ijk is the split-plot error effect.

The binary mixtures (treatments) were considered as a fixed effect in this initial analysis because of the differences in edaphic and climatic conditions between the study sites. A random effect consisted of block (replicates) nested within year and the two-way interaction, treatments by harvest dates were also determined. The Satterthwaite option was used to estimate denominator degrees of freedom. Least square means were separated using Tukey procedure and difference considered significant when $P < 0.05$. The data were expressed as mean $\pm$ standard error (SE).

3.3 Results

3.3.1 Climate Data

Monthly temperature (^{o}C) and precipitation (mm) data from 2016 to 2017 and long-term average (LTA; 30 yrs) were obtained from Saskatoon Research Farm and Swift Current Research Development Center in Saskatchewan according to Environmental Canada’s climatic data online (www.climate.weatheroffice.ec.gc.ca) which is 1 km east of either study sites. In 2016, total precipitation during the growing season was 2.5% lower than the LTA at AAFC Saskatoon and 29% higher than the LTA at AAFC SCRDC site. The total precipitations recorded in 2017 were 31 and 49% below LTA at AAFC Saskatoon and AAFC SCRDC, respectively (Tables 3.3 and 3.4). This was particularly noticeable from March to September at AAFC SCRDC, and June to September at AAFC Saskatoon. The average monthly temperatures varied among yrs but followed similar pattern as the long-term averages recorded at the two study sites. The precipitation data in 2016 reflects a cool and wet season for forage production at both sites. Comparatively, 2017 was warm and dry that resulted in severe drought conditions.

Table 3.3. Monthly Average Temperature and Precipitation and Long-Term Averages at AAFC Saskatoon (2015, 2016, 2017)

	Temperature				Precipitation			
	2015	2016	2017	LTA	2015	2016	2017	LTA[z]
Months	---------------^{o}C-----------------				--------------------mm--------------			
January	-11.8	-12.9	-13	-15.2	5.8	17.3	7.4	13.8
February	-17.4	-7.9	-9.3	-11.6	16.5	7.0	9.1	8.8
March	-2.4	-1.5	-5.2	-5.7	5.1	13.9	11.3	11.9
April	5.6	5.5	4.3	4.3	21.1	3.0	18.4	21.0
May	10.1	13.7	12.1	11.1	0.4	41.6	46.3	41.3
June	17.2	17.4	16.1	16.1	13.6	49.7	30.9	73.1
July	19.4	18.7	19.6	18.5	84.3	58.6	25.5	60.3
August	17.4	16.9	17.8	17.4	45.2	70.2	25.2	48.2
September	11.9	11.8	12.8	12.3	50.0	24.1	29.1	31.6
October	6.7	2.1	5.0	4.1	33.9	40.8	17.8	19.1
November	-3.0	1.9	-9.8	-5.6	14.0	9.2	15.4	13.7
December	-9.3	-13.7	-12.3	-13.2	2.5	9.7	6.9	11.4
Total -mean	3.7	4.3	3.2	2.7	292.4	345.1	243.3	354.2

[z]LTA = Long term average (30 yrs)

Table 3.4. Monthly Average Temperature and Precipitation and Long-Term Averages at AAFC SCRDC (2015, 2016, 2017)

	Temperature				Precipitation			
	2015	2016	2017	LTA	2015	2016	2017	LTA[z]
Months	------------------°C------------				-----------------mm---------------			
January	-8.2	-8.3	-10.3	-10.9	7.9	3.1	5.6	12.4
February	-11.1	-3.1	-7.1	-8.6	12.9	2.2	14.3	9.2
March	0.9	1.4	-2.4	-2.9	8.4	6.5	6.4	15.9
April	6.1	6.4	4.4	4.9	12.4	22.0	8.6	22.6
May	10.1	12.4	12.1	10.9	2.3	129.7	16.4	47.9
June	17.1	16.6	15.2	15.5	16.1	80.4	31.1	80.9
July	19.0	17.8	20.4	18.4	96.1	119	7.5	53.3
August	18.2	16.7	18.2	17.9	49.2	45.9	24.8	47.8
September	12.6	12.2	13.4	12.8	39.0	37.1	2.5	32.5
October	7.8	4.1	4.8	5.2	33.8	72.1	51.7	20.3
November	-1.1	3.6	-4.8	-3.0	17.2	0.2	13.5	14.6
December	-6.4	-12.6	-9.9	-9.5	8.7	4.4	6.8	14.7
Total- mean	5.4	5.6	4.5	4.2	304.0	522.6	189.2	372.1

[z]LTA = Long term average (30 yrs)

3.3.2 Forage Dry Matter Yield and Botanical Composition of Binary Mixture

Forage DM yield of the tame binary mixtures at AAFC Saskatoon and AAFC SCRDC are presented in Table 3.5 and 3.6, respectively. Dry matter yield differed (P = 0.01) among treatments within and across yrs, and July and September harvest dates (yr 2) at both study sites. There were no significant differences (P > 0.05) between treatments by harvest date interactions for forage production at both sites.

Dry matter yield of the native binary mixtures at AAFC SCRDC are presented in Table 3.7. Dry matter yield differed (P = 0.01) among treatments within and across yrs, and July and September harvest date (yr 2) at both study sites.

At AAFC Saskatoon, the ALF-HBG mixture ranked the highest in yield both within and across yrs (10,113 kg ha^{-1}), followed by the CMV- HBG mixture. The MSF-HBG mixture had intermediate yield whilst NSF-RWR had the lowest yield (4,511 kg ha^{-1}) (Table 3.5). At AAFC SCRDC, however, the CMV- HBG mixture ranked the highest in yield both within and across yrs (4,826 kg ha^{-1}), followed by the ALF-HBG mixture (Table 3.6). The MSF-HBG mixture had intermediate yield whilst the NSF-RWR mixture had the lowest yield (1,828 kg ha^{-1}) (Table 3.6). Although the biomass yield was analyzed separately due to edaphic and climatic conditions, DM yield at AAFC Saskatoon site was two-fold higher (P = 0.01) than at AAFC SCRDC site.

For the native binary mixtures at AAFC SCRDC, PPC-HBG mixture ranked the highest for biomass yield (3,582 kg ha^{-1}), while the WPC-RWR mixture had the lowest yield (884 kg ha^{-1}) (Table 3.7). The GCM- HBG mixture ranked the third highest yield (2,745 kg ha^{-1}) followed by the WPC-HBG mixture with 2,534 kg ha^{-1} (Table 3.7).

Year of harvesting forages at both sites were greater (P < 0.05) in 2016 than 2017. The July harvest of all binary mixtures were 15 to 22% greater (P = 0.01) compared to the September harvest date at both sites.

The botanical composition of grass species in each mixture for tame legumes at AAFC Saskatoon is presented in Figures 3.1 and 3.2, and AAFC SCRDC in Figures 3.3 and 3.4, and for native legumes at AAFC SCRDC is presented in Figures 3.5 and 3.6. At AAFC Saskatoon, the composition of the grass was greater (P = 0.01) in September harvest for MSF-HBG and greater (P = 0.01) in July harvest for CMV- MBG and CMV-HBG mixtures among treatments in 2016. In 2017, composition of grass was greater (P = 0.01) in MSF-RWR, MSF-MBG, CMV-MBG, CMV-RWR, ALF-HBG, NSF- MBG, SSF-MBG (P = 0.03), mixtures among treatments. At

AAFC SCRDC, for tame mixtures, the grass composition was greater in September harvest for MSF-RWR (*P* = 0.05), MSF- MBG (*P* = 0.03), DSF-RWR (*P* = 0.02) and ALF-HBG (*P* = 0.05) mixtures among treatments in 2017.

Russian wildrye in mixtures with tame or native legumes produced the lowest yield while hybrid bromegrass grass had the highest yield in a mixture. The composition of grass in mixtures was 25 to 29% greater at the September harvest date compared to the July harvest date at both sites. However, this was different ($P < 0.05$) in grass species in the CMV- MBG mixture at AAFC Saskatoon.

Table 3.5. Dry Matter Yield of Tame Binary Mixtures at AAFC Saskatoon in 2016 and 2017

Treatment[z]	2016	2017	Mean (2016-2017)
	---------------------------------	kg ha^{-1}	-------------------------------------
MSF-HBG	7135ab	8255abc	7695abcd
MSF- MBG	6929ab	7525abc	7227bcde
MSF-RWR	6394ab	5408bcd	5901de
CMV- HBG	9581ab	8897ab	9239ab
CMV- MBG	7987ab	6605abcd	7296abcde
CMV- RWR	8205ab	7704abc	7668abcde
ALF-HBG	10491a	9735a	10113a
ALF- MBG	8972ab	7249abcd	8110abcd
ALF-RWR	8588ab	7070abcd	7829abcd
NSF-HBG	7791ab	5275bcd	6533bcde
NSF- MBG	7071ab	4609cd	5840de
NSF-RWR	5209b	3813d	4511e
SSF-HBG	9626a	7914abc	8770abc
SSF- MBG	7761ab	5373bcd	6567bcde
SSF-RWR	6409ab	6008bcd	6208cde
SEM	893.18	745.43	821.72
P-value	**< 0.01**	**< 0.01**	**< 0.01**
Harvest date			
July	8260	7671a	7910a
September	7494	5853b	6691b
SEM	326.14	272.19	599.59
P-*v*alue	0.10	**< 0.01**	**< 0.01**
Treatment x harvest date			
SEM	1263.15	1054.19	1018.53
P-*v*alue	0.08	0.55	0.12

[z]MSF = AC Mountainview sainfoin; ALF = AC Yellowhead alfalfa; HBG = AC Success hybrid bromegrass; RWR = Tom Russian wildrye; CMV = AC Veldt cicer milkvetch; NSF = Nova sainfoin; SSF = Shoshone sainfoin; MBG = Admiral meadow bromegrass.
SEM = standard error of the mean
[a-e] Means within a column with different letters differ (P < 0.05).

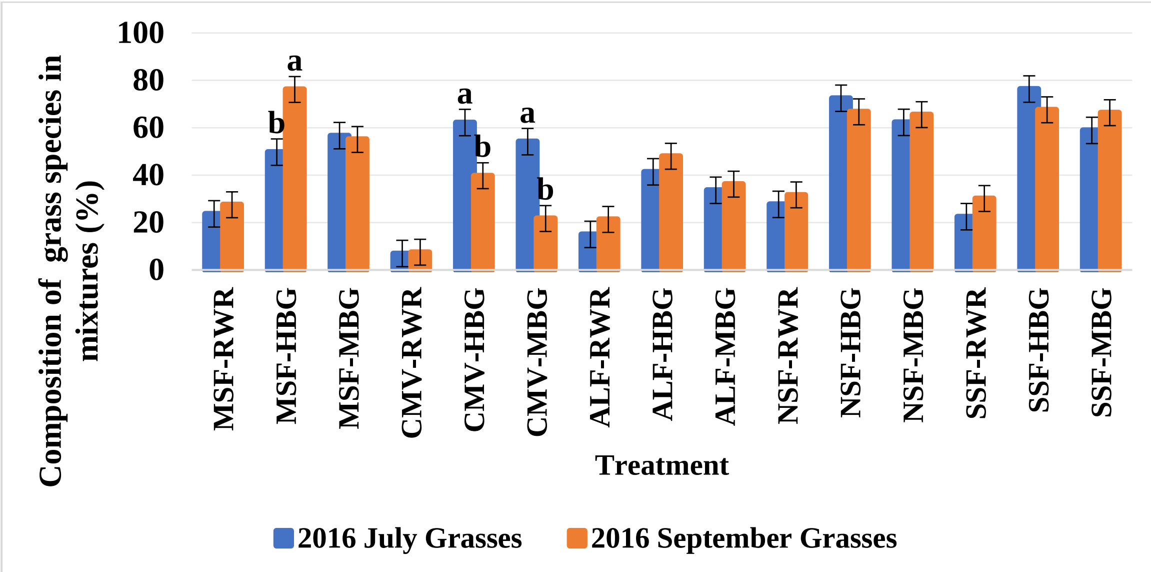


Figure 3.1. Percent Botanical Composition of Grass Species in Tame Binary Mixtures at AAFC Saskatoon in 2016

ALF= AC Yellowhead alfalfa; HBG=AC Success hybrid bromegrass; MSF= AC Mountainview sainfoin; RWR= Tom Russian wildrye; CMV= AC Veldt cicer milkvetch; NSF= Nova sainfoin; SSF= Shoshone sainfoin; MBG = Admiral meadow bromegrass

Vertical bars = standard error of the mean

[a-b] Means with different letters differ (P < 0.05).

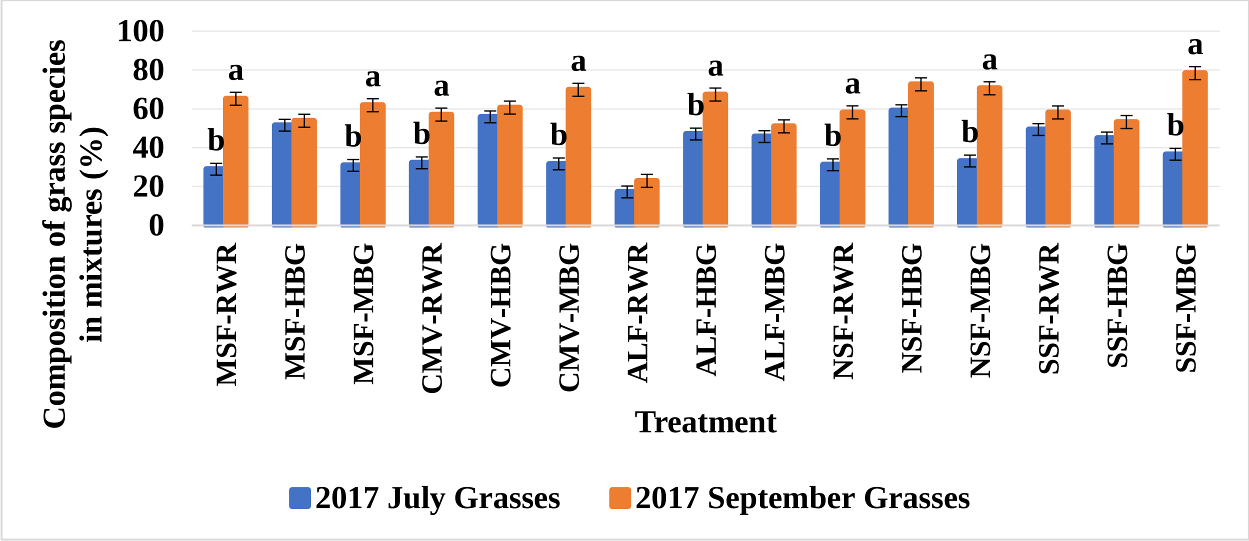


Figure 3.2. Percent Botanical Composition of Grass Species in Tame Binary Mixtures at AAFC Saskatoon in 2017.

ALF= AC Yellowhead alfalfa; HBG=AC Success hybrid bromegrass; MSF= AC Mountainview sainfoin; RWR= Tom Russian wildrye; CMV= AC Veldt cicer milkvetch; NSF= Nova sainfoin; SSF= Shoshone sainfoin; MBG = Admiral meadow bromegrass

Vertical bars = standard error of the mean

[a-b] Means with different letters differ ($P < 0.05$).

Table 3.6. Dry Matter Yield of Tame Binary Mixtures at AAFC SCRDC in 2016 and 2017			
Treatment[z]	2016	2017	Mean (2016-2017)
	-----------------------------kg ha^{-1}---------------------------------------		
MSF-HBG	3461bcde	2823cde	3142cdef
MSF- MBG	3682abcde	2285defg	2984def
MSF-RWR	2757de	1970efgh	2363efg
CMV- HBG	5657a	3995a	4826a
CMV- MBG	4501abcd	3014bcd	3757abcd
CMV- RWR	3130bcde	2206defgh	2667defg
ALF-HBG	5105ab	3757ab	4431ab
ALF- MBG	5050abc	3299abc	4174abc
ALF-RWR	4153abcde	2535cdef	3344bcde
NSF-HBG	3050cde	2251defgh	2650defg
NSF-MBG	3350bcde	2197defgh	2774defg
NSF-RWR	2149e	1507gh	1828g
SSF-HBG	3422bcde	2626cdef	3024def
SSF- MBG	3551bcde	2313defg	2932defg
SSF-RWR	2413e	1738fgh	2075fg
DSF-HBG	3446bcde	2115efgh	2780defg
DSF- MBG	3614bcde	1882fgh	2748defg
DSF-RWR	2660de	1387h	2024fg
SEM	398.29	175.63	630.86
P-value	**< 0.01**	**< 0.01**	**< 0.01**
Harvest date			
July	3631	3107a	3369a
September	3608	1770b	2689b
SEM	132.76	58.54	592.87
P-value	0.90	**<0.01**	**< 0.01**
Treatment x harvest date			
SEM	563.26	248.38	671.03
P-value	0.93	0.20	0.63

[z]ALF = AC Yellowhead alfalfa; HBG = AC Success hybrid bromegrass; MSF = AC Mountainview sainfoin; RWR = Tom Russian wildrye; CMV = AC Veldt cicer milkvetch; NSF = Nova sainfoin; SSF = Shoshone sainfoin; DSF = Delaney sainfoin; MBG = Admiral meadow bromegrass.

AAFC SCRDC **=** Agriculture and Agri-Food Canada of Swift Current Research Development Centre

SEM = standard error of the mean

[a-h] Means within a column with different letters differ (P < 0.05).

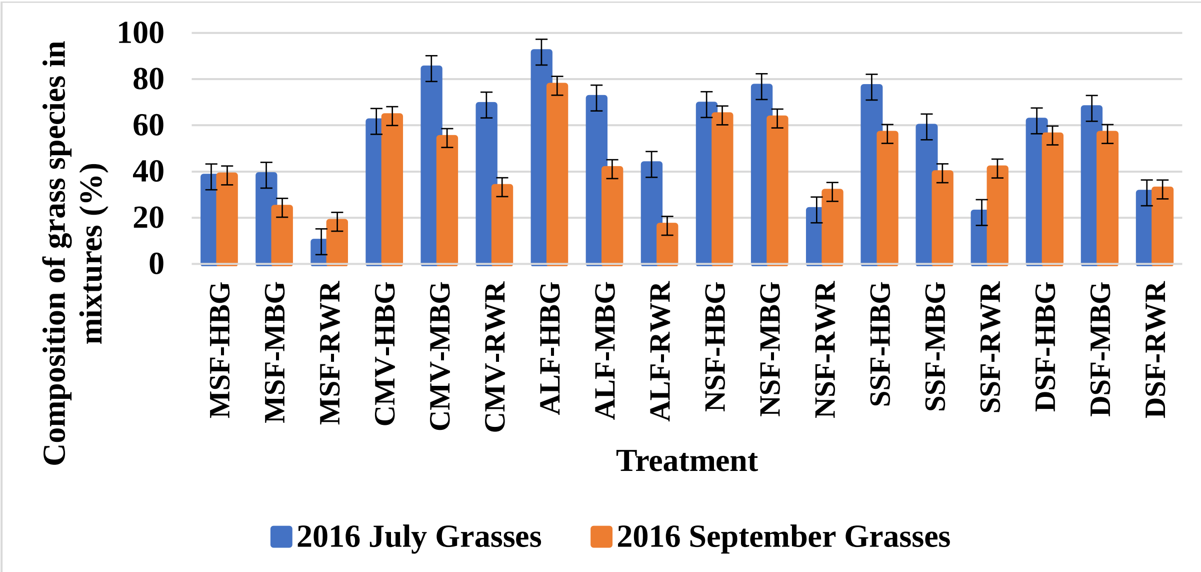


Figure 3.3. Percent Botanical Composition of Grass Species in Tame Binary Mixtures at AAFC SCRDC in 2016.

ALF = AC Yellowhead alfalfa; HBG = AC Success hybrid bromegrass; MSF = AC Mountainview sainfoin; RWR = Tom Russian wildrye; CMV= AC Veldt cicer milkvetch; NSF = Nova sainfoin; SSF = Shoshone sainfoin; DSF = Delaney sainfoin; MBG = Admiral meadow bromegrass.

AAFC SCRDC **=** Agriculture and Agri-Food Canada of Swift Current Research Development Centre

Vertical bars = standard error of the mean

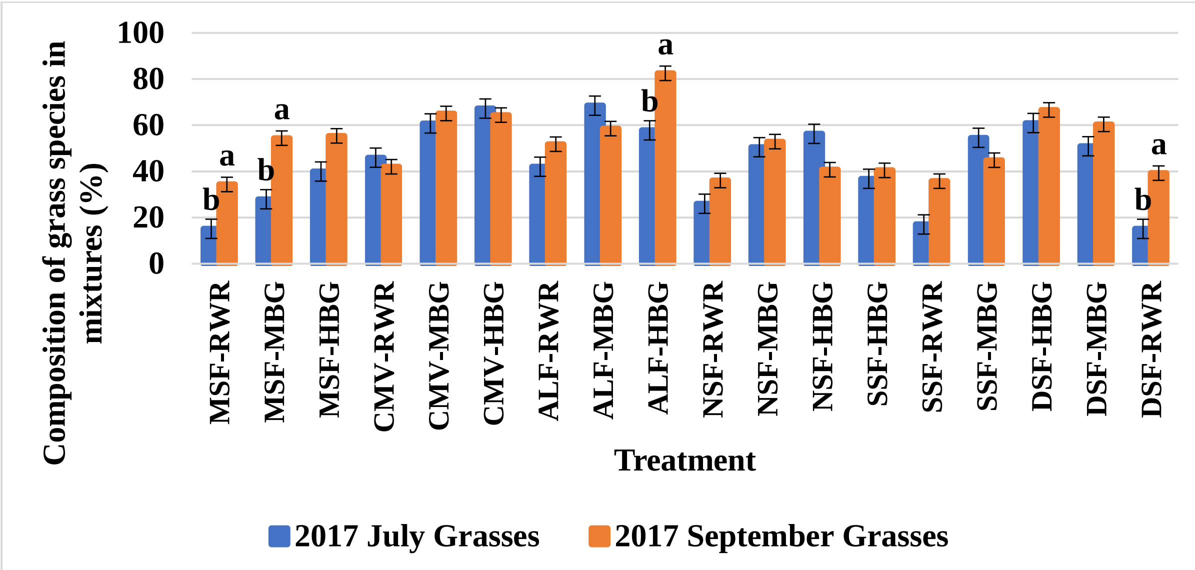


Figure 3.4. Percent Botanical Composition of Grass Species in Tame Binary Mixtures at AAFC SCRDC in 2017.

ALF = AC Yellowhead alfalfa; HBG = AC Success hybrid bromegrass; MSF = AC Mountainview sainfoin; RWR = Tom Russian wildrye; CMV, AC Veldt cicer milkvetch; NSF = Nova sainfoin; SSF, Shoshone sainfoin; DSF = Delaney sainfoin; MBG = Admiral meadow bromegrass.

AAFC SCRDC **=** Agriculture and Agri-Food Canada of Swift Current Research Development Centre

Vertical bars = standard error of the mean

[a-b] Means with different letters differ (P < 0.05).

Table 3.7. Dry Matter Yield of Native Legume Binary Mixtures at AAFC SCRDC in 2016 and 2017

Treatment[z]	2016	2017	Mean (2016-2017)
	------------------------------kg ha^{-1}------------------------------		
GCM-HBG	3370ab	2163ab	2745ab
GCM-MBG	3451ab	1496bc	2473bc
GCM-RWR	1366cd	653c	1009d
PPC-HBG	4630a	2535a	3582a
PPC-MBG	4452a	1661ab	3056ab
PPC-RWR	2006bcd	1282bc	1644cd
WPC-HBG	3088abc	1980ab	2534abc
WPC-MBG	3181ab	1820ab	2500bc
WPC-RWR	1140d	624c	884d
SEM	394.69	201.87	725.97
P-value	**<0.01**	**<0.01**	**<0.01**
Harvest date			
July	3148	1966a	2557a
September	2782	1193b	1982b
SEM	186.06	95.16	695.13
P-value	0.17	**<0.01**	**<0.01**
Treatment x Harvest date			
SEM	558.18	285.49	773.04
P-value	0.43	0.77	0.44

[z]HBG = AC Success hybrid bromegrass; RWR = Tom Russian wildrye; MBG = Admiral meadow bromegrass; WPC = AC Antelope white prairie clover; PPC = AC Lamour purple prairie clover; GCM = Great Plains-Ecovar Canadian milkvetch.
AAFC SCRDC = Agriculture and Agri-Food Canada of Swift Current Research Development Centre
SEM = standard error of the mean
[a-d] Means within a column with different letters differ (P < 0.05).

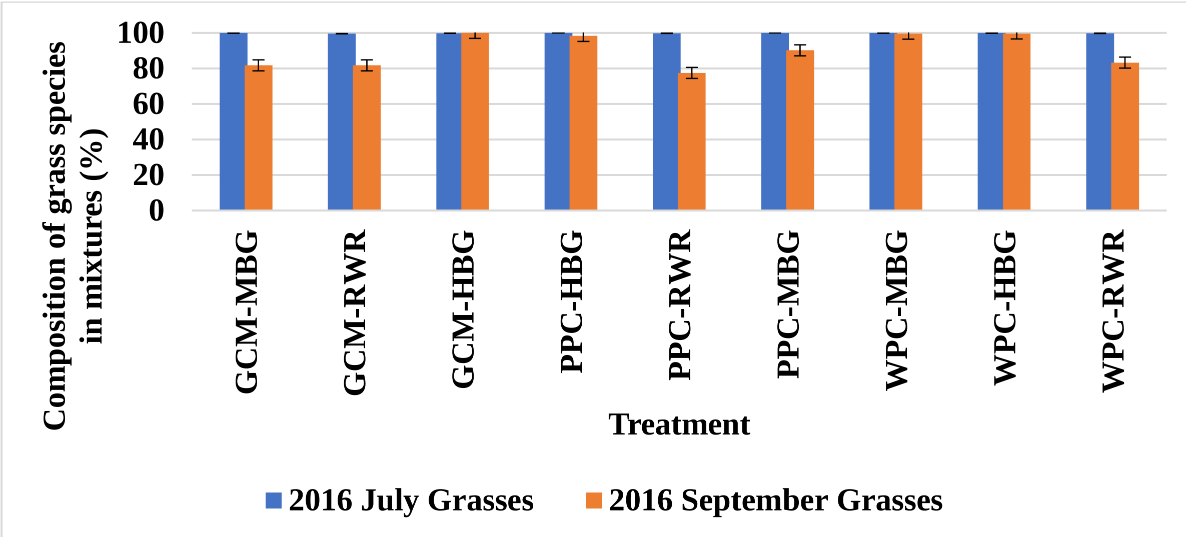


Figure 3.5. Percent Botanical Composition of Grass Species in Native Binary Mixtures at AAFC SCRDC in 2016.

^{z}HBG = AC Success hybrid bromegrass; RWR = Tom Russian wildrye; MBG = Admiral meadow bromegrass; WPC = AC Antelope white prairie clover; PPC = AC Lamour purple prairie clover; GCM = Great Plains-Ecovar Canadian milkvetch

AAFC SCRDC **=** Agriculture and Agri-Food Canada of Swift Current Research Development Centre

Vertical bars = standard error of the mean

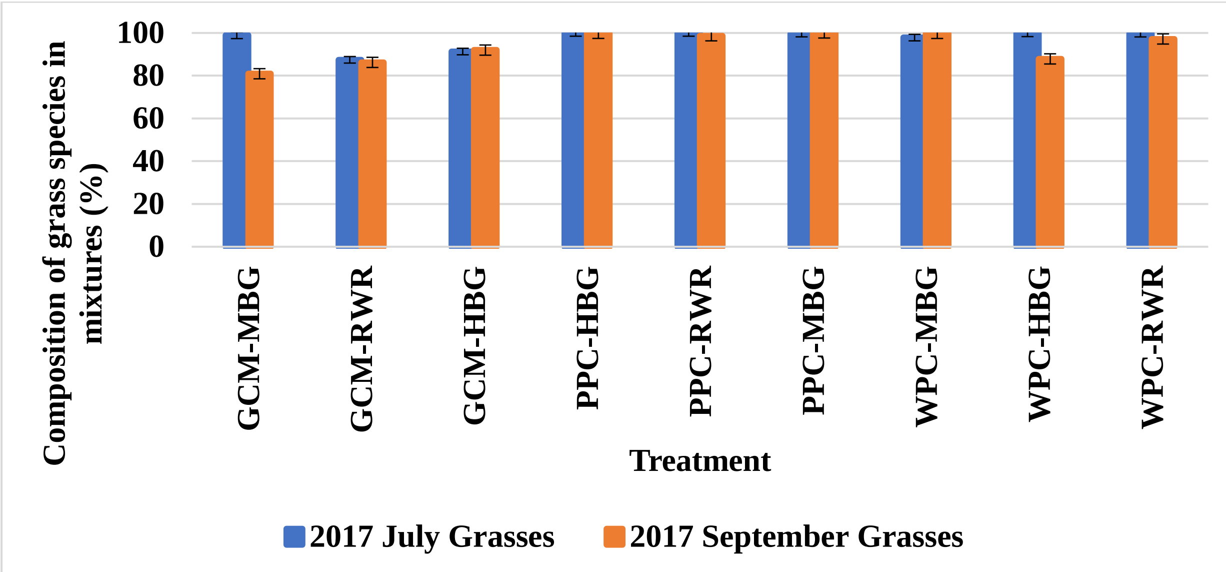


Figure 3.6. Percent Botanical Composition of Grass Species in Native Binary Mixtures at AAFC SCRDC in 2017.
HBG = AC Success hybrid bromegrass; RWR = Tom Russian wildrye; MBG = Admiral meadow bromegrass; WPC = AC Antelope white prairie clover; PPC = AC Lamour purple prairie clover; GCM = Great Plains Ecovar Canadian milkvetch.
Vertical bars = standard error of the mean
AAFC SCRDC = Agriculture and Agri-Food Canada of Swift Current Research Development Centre

3.3.3 Forage Nutritive Value

All forage nutritive value variables were significantly different (P = 0.01) among the tame binary mixtures at AAFC Saskatoon and AAFC SCRDC (Tables 3.8 and 3.9), respectively and native binary mixtures (Tables 3.10). Acid detergent fibre, OM, CP and P concentrations differed (P = 0.01) between treatment by harvest date interactions of native binary mixtures in 2016. However, only NDF concentration differed (P = 0.02) between treatment by harvest date interactions of native binary mixtures in 2017 (Table 3.10).

All forage nutritive value variables differed (P < 0.01) between harvest dates of tame binary mixtures in both yrs at AAFC SCRDC and 2016 at AAFC Saskatoon. *In vitro* organic matter digestibility and CP concentration decreased while fibre and ADL concentrations increased simultaneously from July to September harvest dates at both sites.

All forage nutritive value variables differed (P < 0.05) between treatment by harvest date interactions of tame binary mixtures in 2016 at AAFC SCRDC (Table 3.9). In 2017, however, no significant (P > 0.05) treatment by harvest interactions were observed for forage nutritive value.

All forage nutritive value variables except NDF and P concentrations differed (P < 0.05) between treatment by harvest date interactions of tame binary mixtures in 2016 at AAFC Saskatoon. In 2017, however, ADF and TDN level differed (P = 0.01) between treatment by harvest date interactions of tame binary mixtures at AAFC Saskatoon (Table 3.8).

Table 3.8. Nutritive Value of Tame Binary Mixtures at AAFC Saskatoon

Treatment[z]	OM[y]	IVOMD	ADF	NDF	ADL	CP	P	Ca	TDN
2016	-----------------------------	----------	----------	----------	%	----------	----------	----------	-----------------------------
MSF-HBG	94.0a	54.2ab	45.6abc	60.8a	10.9abcd	6.2ef	0.10ab	0.62cd	48.9abc
MSF-RWR	94.1a	56.4ab	46.5abc	55.2ab	9.7bcd	9.4bcde	0.12ab	1.06abc	47.9abc
MSF- MBG	94.2a	54.5ab	46.2abc	60.3a	10.5abcd	6.5def	0.10ab	0.79abcd	48.3abc
CMV- RWR	90.6d	59.6ab	39.6bc	45.5b	11.4abc	13.1a	0.15a	1.15ab	55.1ab
CMV- HBG	91.3bc	60.0a	39.5bc	51.1ab	8.8cd	9.9abcd	0.13ab	0.98abcd	55.2ab
CMV- MBG	92.1bc	58.0ab	39.1c	51.2ab	10.9abcd	9.8abcd	0.13ab	0.98abcd	55.6a
ALF-RWR	93.2ab	55.9ab	49.7a	61.7a	11.3abc	11.2ab	0.14ab	1.16a	44.7c
ALF-HBG	93.7a	53.2b	48.1a	61.3a	10.8abcd	9.4bcde	0.12ab	1.04abc	46.3c
ALF- MBG	92.9ab	55.9ab	45.5abc	56.4ab	9.1cd	9.5bcde	0.13ab	0.95abcd	49.0abc
NSF- MBG	94.2a	53.6ab	47.4a	62.9a	12.4a	5.9f	0.09b	0.68bcd	46.9c
NSF-RWR	93.6a	54.9ab	46.7ab	55.6ab	12.2ab	8.6bcdef	0.12ab	0.89abcd	47.7bc
NSF-HBG	93.8a	55.5ab	43.9abc	58.1ab	9.4cd	6.9cdef	0.12ab	0.65cd	50.6abc
SSF-HBG	94.3a	53.2ab	44.6abc	59.7a	8.6d	6.8cdef	0.12ab	0.54d	49.9abc
SSF-RWR	93.7a	54.9ab	44.3abc	51.7ab	11.4abc	10.1abc	0.13ab	1.05abc	50.2abc
SSF- MBG	93.9a	55.1ab	43.3abc	61.9a	9.5cd	6.9cdef	0.12ab	0.63cd	51.3abc
SEM	0.30	1.38	1.53	2.62	0.54	0.70	0.01	0.09	1.58
P-value	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**0.03**	**<0.01**	**<0.01**
Harvest date									
July	93.3	59.5a	39.7b	51.0b	9.7b	10.0a	0.15a	0.86	55.0a
September	93.4	51.8b	49.7a	62.8a	11.3a	7.4b	0.09b	0.89	44.7b
SEM	0.11	0.50	0.56	0.97	0.19	0.26	0.01	0.03	0.58
P-value	0.13	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	0.54	**<0.01**
Treatment x harvest date									
SEM	0.43	1.96	2.16	3.72	0.77	0.99	0.01	0.13	2.33
P-value	**<0.01**	**<0.01**	**0.04**	0.12	**<0.01**	**<0.01**	0.13	**<0.01**	**0.04**

Table 3.8. Nutritive Value of Tame Binary Mixtures at AAFC Saskatoon (continued)									
Treatment[z]	OM[y]	IVOMD	ADF	NDF	ADL	CP	P	Ca	TDN
2017	--				-%-	--			
MSF-HBG	93.7a	53.8ab	46.0abcde	56.5	12.9ab	5.1cd	0.07	0.71de	48.5abcde
MSF-RWR	92.0bcde	53.6ab	51.1ab	58.8	12.6ab	6.7bc	0.08	0.84bcde	43.2de
MSF- MBG	92.4abcd	54.9ab	46.2abcde	60.2	12.0abc	5.3cd	0.09	0.74de	48.2abcde
CMV-RWR	90.7e	56.2ab	45.8bcde	62.5	10.7abc	7.6ab	0.08	1.24a	48.7abcd
CMV- HBG	91.9bcde	55.8ab	41.1e	59.0	8.7c	6.0bcd	0.08	0.84bcde	53.6a
CMV- MBG	90.7de	57.3a	42.8e	56.3	10.5bc	6.6bc	0.09	1.04abcd	51.7a
ALF-RWR	91.5cde	52.1b	50.1abc	60.7	12.7ab	8.8a	0.09	1.20ab	44.2cde
ALF-HBG	92.9abc	52.5b	49.1abcd	60.2	10.8abc	5.7cd	0.07	0.95abcde	45.3bcde
ALF- MBG	91.9bcde	53.7ab	44.1de	61.7	12.6ab	6.7bc	0.08	1.13abc	50.4ab
NSF- MBG	92.1abcde	55.5ab	45.2cde	61.3	11.3abc	5.6cd	0.08	0.89abcde	49.3abc
NSF-RWR	92.2abcde	54.6ab	45.5bcde	60.0	14.2a	6.6bc	0.07	0.91abcde	48.9abcd
NSF-HBG	92.9abc	55.5ab	42.4e	59.5	10.0bc	4.3d	0.08	0.63e	52.2a
SSF-HBG	93.5ab	52.8ab	51.7a	61.4	12.6ab	5.2cd	0.08	0.64e	42.6e
SSF-RWR	91.8bcde	54.8ab	45.5bcde	64.2	11.9abc	6.6bc	0.08	0.83bcde	48.9abcd
SSF- MBG	92.8abc	55.3ab	44.1de	63.0	11.1abc	5.8cd	0.08	0.78cde	50.4ab
SEM	0.34	0.96	1.18	2.1	0.71	0.35	0.01	0.08	1.22
P-value	**<0.01**	**0.01**	**<0.01**	0.39	**<0.01**	**<0.01**	0.07	**<0.01**	**<0.01**
Harvest date									
July	92.3	58.6a	41.9b	60.6	10.2b	7.1a	0.10a	0.87	52.7a
September	92.1	50.3b	50.1a	60.1	13.0a	5.2b	0.06b	0.92	44.2b
SEM	0.12	0.35	0.43	0.77	0.26	0.13	<0.01	0.03	0.44
P-value	0.21	**<0.01**	**<0.01**	0.68	**<0.01**	**<0.01**	**<0.01**	0.18	**<0.01**
Treatment x harvest date									
SEM	0.49	1.36	1.67	2.99	1.00	0.50	<0.01	0.11	1.73
P-value	**<0.01**	0.23	**<0.01**	0.08	0.06	0.07	0.18	0.43	**<0.01**

[z]ALF = AC Yellowhead alfalfa; HBG = AC Success hybrid bromegrass; MSF = AC Mountainview sainfoin; RWR = Tom Russian wildrye; NSF = Nova sainfoin; SSF = Shoshone sainfoin; CMV= AC Veldt cicer milkvetch; MBG = Admiral meadow bromegrass;
[y]OM = organic matter; OMD = organic matter digestibility; ADF = acid detergent fibre; NDF = neutral detergent fibre; ADL= acid detergent lignin; CP = crude protein; P = phosphorus; Ca = calcium, TDN, total digestible nutrient;
SEM = standard error of the mean.
[a-f] Means within a column with different letters differ (*P* < 0.05).

Table 3.9. Nutritive Value of Tame Binary Mixtures at AAFC SCRDC

Treatment[z]	OM[y]	IVOMD	ADF	NDF	ADL	CP	P	Ca	TDN
2016	----------------------------	----------------------------	----------------------------	----------------------------	--------%--------	----------------------------	----------------------------	----------------------------	----------------------------
MSF-RWR	94.2a	49.5abc	43ab	55.8ab	11.1a	6.4bc	0.14ab	0.68abc	51.5bc
MSF-MBG	93abc	49.8abc	42.2ab	57.1ab	9.1abc	5.1bcde	0.14ab	0.55abcd	52.4bc
MSF-HBG	93.8ab	49.7abc	42.1ab	56.4ab	9.9abc	5.2bcde	0.14ab	0.51abcd	51.8bc
CMV-RWR	91.9c	54.0a	36.6c	53.0b	7.4bc	9.4a	0.16ab	0.58abcd	58.2a
CMV-MBG	91.8c	53.8ab	40.1bc	58.1ab	7.4bc	5.6bcd	0.14ab	0.46cd	54.6ab
CMV-HBG	93abc	49.1bc	41.2b	60.2a	7.9abc	4.9bcde	0.13b	0.36d	53.4b
ALF-HBG	93.5ab	47.2c	42.8ab	60.0a	7.6abc	4.5bcde	0.21ab	0.51abcd	50.6bc
ALF-RWR	93.5ab	48.7c	45.8a	59.6a	10.0abc	7.2ab	0.26ab	0.74a	48.7c
ALF-MBG	92.7bc	48.6c	44.4ab	61.6a	8.3abc	4.4bcde	0.26ab	0.57abcd	50.0bc
NSF-HBG	93.1abc	48.7c	41.9ab	57.9ab	9.6abc	4.4bcde	0.14ab	0.47bcd	52.7bc
NSF- MBG	92.7bc	50.1abc	42.4ab	59.2ab	8.8abc	4.5bcde	0.14ab	0.47bcd	52.1bc
NSF-RWR	93.5ab	48.6c	41.9ab	55.4ab	10.4ab	6.5b	0.15ab	0.71ab	52.7bc
SSF-RWR	93.6ab	48.3c	42.9ab	59.7ab	6.3c	2.7de	0.36ab	0.65abc	51.7bc
SSF- MBG	93abc	48.0c	43.8ab	61.5a	7.5bc	3.4de	0.18ab	0.44cd	51.0bc
SSF-HBG	94.2ab	46.3c	43.4ab	61.1a	7.8abc	3.0de	0.17ab	0.38d	50.4bc
DSF- MBG	92.6bc	50.3abc	41.2abc	57.5ab	-	2.2e	0.33ab	0.47bcd	52.8bc
DSF-HBG	93.4abc	49.1abc	41.7ab	57ab	-	2.1e	0.30ab	0.49bcd	53.6ab
DSF-RWR	93.7ab	49.8abc	42.1ab	56.7ab	-	3.3cde	0.42a	0.63abc	52.3bc
SEM	0.30	1.00	0.92	1.39	0.70	0.60	0.05	0.05	0.92
P-value	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**
Harvest date									
July	92.9b	54.1a	38.1b	53.8b	6.0a	4.6	0.31a	0.55	56.4a
September	93.4a	44.7b	46.3a	62.7a	-	4.8	0.10b	0.52	48.1b
SEM	0.1	0.34	0.31	0.46	0.23	0.2	0.02	0.02	1.21
P-value	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	0.33	**<0.01**	0.24	**<0.01**
Treatment x harvest date									
SEM	0.43	1.42	1.29	1.96	1.03	0.85	0.08	5.72	1.31
P-value	**<0.01**	**0.04**	**<0.01**	**0.04**	**<0.01**	**<0.01**	**<0.01**	**0.05**	**0.02**

Table 3.9. Nutritive Value of Tame Binary Mixtures at AAFC SCRDC (continued)

Treatment[z]	OM[y]	IVOMD	ADF	NDF	ADL	CP	P	Ca	TDN
2017	---				%				---
MSF-RWR	93.0a	53.7abcd	41.6abc	54.7ab	11.0ab	4.7bcde	0.06ab	0.70ab	53.5bcd
MSF- MBG	93.7a	53.4abcd	41.3abcd	56.7a	9.8abc	4.1cde	0.06ab	0.64b	53.9bcd
MSF-HBG	94.3a	52.4bcd	41.1abcd	56.6a	9.8abc	3.9cde	0.06ab	0.60bc	54.2bc
CMV- RWR	91.2a	59.2a	35.6e	48.7b	8.0c	6.8a	0.07a	0.77a	59.6a
CMV- MBG	92.5a	58.1ab	37.1cde	52.7ab	7.8c	5.1bc	0.06ab	0.69b	57.8abc
CMV- HBG	93.3a	56.4abc	36.9de	52.7ab	7.9c	4.9bcd	0.06ab	0.58bc	58.2ab
ALF-HBG	92.5a	51.9bcd	38.9bcde	56.7a	8.6bc	4.7bcde	0.05ab	0.73ab	56.5abcd
ALF-RWR	83.4b	48.9d	39.9abcde	53.6ab	10.5ab	5.6b	0.05b	0.75ab	55.3bcd
ALF- MBG	92.7a	52.4bcd	41.7ab	59.3a	9.4abc	4.4bcde	0.05ab	0.76ab	53.0d
NSF-HBG	94.2a	51.8bcd	41abcd	57.1a	9.4abc	3.5e	0.06ab	0.58bc	54.2bcd
NSF- MBG	93.0a	52.6bcd	41.6abc	56.7a	10abc	3.8de	0.06ab	0.64b	53.4bcd
NSF-RWR	93.2a	53.6abcd	42.3ab	55.2ab	11.1a	4.6bcde	0.06ab	0.75ab	52.9d
SSF-RWR	92.1a	52.7bcd	42.0ab	54.5ab	10.7ab	4.6bcde	0.06ab	0.69b	53.3cd
SSF- MBG	92.2a	50.6cd	43.2a	57.1a	10.4ab	3.7e	0.06ab	0.60bc	51.7d
SSF-HBG	93.1a	51.3cd	41.6ab	57.0a	9.9abc	3.7e	0.06ab	0.57bc	53.6cd
DSF- MBG	93.0a	52.7bcd	41abcd	57.5a	9.4abc	3.9cde	0.06ab	0.66b	54.1bcd
DSF-HBG	93.0a	53.1abcd	40.1abcd	56.7a	9.0abc	3.9de	0.06ab	0.60	55.3abcd
DSF-RWR	92.4a	52.9bcd	41.1abcd	54.3ab	10abc	4.8bcde	0.06ab	0.77a	54.1bcd
SEM	1.42	1.28	0.91	1.40	0.47	0.25	0.01	0.05	0.96
P-value	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**0.01**	**0.05**	**<0.01**
Harvest date									
July	93.2a	55.1a	36.9b	50.6b	8.9b	5.3a	0.07a	0.73a	58.5a
September	91.5b	51.3b	44a	60.3a	10.3a	3.7b	0.04b	0.61b	50.9b
SEM	0.47	0.43	0.3	0.47	0.16	0.8	<0.01	0.02	0.32
P-value	**0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**
Treatment x harvest date									
SEM	2.00	1.81	1.28	1.98	0.67	0.35	<0.01	0.08	1.35
P-value	1.00	1.00	0.96	0.80	0.89	0.43	0.33	0.06	0.92

[z]ALF = AC Yellowhead alfalfa; HBG = AC Success hybrid bromegrass; MSF = AC Mountainview sainfoin; RWR = Tom Russian wildrye; NSF = Nova sainfoin; SSF = Shoshone sainfoin; DSF = Delaney sainfoin; CMV = AC Veldt cicer milkvetch; MBG = Admiral meadow bromegrass

[y]OM = organic matter; IVOMD = *in vitro* organic matter digestibility; ADF = acid detergent fibre; NDF = neutral detergent fibre; ADL = acid detergent lignin; CP = crude protein; P = phosphorus; Ca = calcium, TDN = total digestible nutrient.

AAFC SCRDC = Agriculture and Agri-Food Canada of Swift Current Research Development Centre

SEM = standard error of the mean.

[a-e] Means within a column with different letters differ ($P < 0.05$).

Table 3.10. Nutritive Value of Native Legume Binary Mixtures at AAFC SCRDC

Treatment[z]	OM[y]	IVOMD	ADF	NDF	ADL	CP	P	Ca	TDN
2016	--				---%---				--
PPC-HBG	93.1abc	46.0	42.3	62.9	-	1.6d	0.16bc	0.21b	53.1
PPC-MBG	92.7abc	48.0	42.5	63.6	-	1.9d	0.16bc	0.25b	52.3
PPC-RWR	92.9abc	47.0	40.6	64.8	-	3.3bc	0.25a	0.35a	54.1
GCM- MBG	92.1c	48.7	41.7	63.4	6.8ab	3.8b	0.12bc	0.24b	52.9
GCM-RWR	92.8abc	48.0	41.1	63.6	7.7a	7.3a	0.17b	0.37a	53.5
GCM- HBG	93.4ab	45.7	41.8	63.3	7.5ab	3.2bc	0.11c	0.21b	52.8
WPC-RWR	92.6abc	47.4	39.5	61.1	4.5c	3.3bc	0.27a	0.40a	54.9
WPC-HBG	93.6a	45.8	42.5	62.8	6.6ab	1.4d	0.13bc	0.21b	52.3
WPC-MBG	92.0bc	48.8	41.7	62.0	6.5b	2.3cd	0.17b	0.25b	53.2
SEM	0.31	1.11	0.90	1.21	0.24	0.28	0.01	0.17	0.72
P-value	**<0.01**	0.29	0.30	0.68	**<0.01**	**<0.01**	**<0.01**	**<0.01**	0.20
Harvest date									
July	92.9	50.6a	38.5b	59.8b	2.7a	1.9b	0.23a	0.24b	56.5a
September	92.7	43.9b	44.4a	66.3a	-	4.4a	0.12b	0.31a	50.0b
SEM	0.15	0.52	0.4	0.57	0.10	0.13	0.01	<0.01	0.40
P-value	0.52	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**
Treatment x harvest date									
SEM	0.44	1.56	1.18	1.70	0.33	0.39	0.02	0.03	1.01
P-value	**0.01**	0.75	0.63	0.67	**<0.01**	**<0.01**	**<0.01**	0.11	0.54

[z]HBG = AC Success hybrid bromegrass; RWR = Tom Russian wildrye; MBG = Admiral meadow bromegrass; WPC = AC Antelope white prairie clover; PPC = AC Lamour purple prairie clover; GCM = Great Plains Canadian milkvetch;
[y]OM = organic matter; IVOMD, *in vitro* organic matter digestibility; ADF = acid detergent fibre; NDF = neutral detergent fibre; ADL = acid detergent lignin; CP = crude protein; P = phosphorus; Ca = calcium, TDN = total digestible nutrient
AAFC SCRDC = Agriculture and Agri-Food Canada of Swift Current Research Development Centre
SEM = standard error of the mean
[a-d] Means within a column with different letters differ (P < 0.05).

Table 3.10. Nutritive Value of Native Legume Binary Mixtures at AAFC SCRDC (continued)

Treatment[z]	OM[y]	IVOMD	ADF	NDF	ADL	CP	P	Ca	TDN
2017	---%--								
PPC-HBG	93.1ab	53.4ab	36.4c	50.1	7.0c	2.7d	0.05	0.32d	59.4
PPC-MBG	91.9ab	51.6ab	40.0ab	53.2	7.5bc	2.8d	0.06	0.4bcd	54.8
PPC-RWR	89.4bc	53.5ab	38.6abc	53.1	9.5ab	4.7ab	0.07	0.55abc	56.5
GCM- MBG	93.1a	54ab	40.1ab	58.7	8.6abc	3.3cd	0.07	0.40bcd	55.0
GCM-RWR	91.2ab	55.2a	39.1abc	55.5	9.3ab	5.2a	0.07	0.57ab	56.0
GCM- HBG	93.5a	55.1a	37.3bc	56.0	8.0bc	3.6bcd	0.09	0.49abcd	55.1
WPC-RWR	87.6c	51.7ab	39.6ab	57.4	10.1a	4.4abc	0.07	0.58a	55.5
WPC-HBG	92.2ab	49.8b	38.9abc	57.7	8.1bc	2.7d	0.05	0.36d	56.4
WPC-MBG	91.9ab	50.3ab	40.6a	58.6	8.8abc	2.9d	0.06	0.38cd	54.3
SEM	0.81	1.17	0.65	2.68	0.43	0.30	0.01	0.04	1.18
P-value	**<0.01**	**<0.01**	**<0.01**	0.33	**<0.01**	**<0.01**	0.35	**<0.01**	0.15
Harvest date									
July	92.5a	54.6a	35.8b	55.9	7.8b	3.9a	0.07a	0.49a	59.9a
September	90.7b	50.8b	42.1a	55.3	9.3a	3.2b	0.05b	0.41b	51.9b
SEM	0.38	0.55	0.31	1.26	0.20	0.14	0.01	0.02	0.56
P-value	**<0.01**	**<0.01**	**<0.01**	0.77	**<0.01**	**<0.01**	**0.01**	**<0.01**	**<0.01**
Treatment x harvest date									
SEM	1.14	1.65	0.92	3.78	0.61	0.42	0.02	0.06	1.67
P-value	0.08	0.43	0.36	**0.02**	0.63	0.10	0.44	0.55	0.20

[z]HBG = AC Success hybrid bromegrass; RWR = Tom Russian wildrye; MBG = Admiral meadow bromegrass; WPC = AC Antelope white prairie clover; PPC = AC Lamour purple prairie clover; GCM = Great Plains Ecovar Canadian milkvetch;
[y]OM = organic matter; IVOMD = *in vitro* organic matter digestibility; ADF = acid detergent fibre; NDF = neutral detergent fibre; ADL = acid detergent lignin; CP = crude protein; P = phosphorus; Ca = calcium, TDN = total digestible nutrient
AAFC SCRDC = Agriculture and Agri-Food Canada of Swift Current Research Development Centre
SEM = standard error of the mean
[a-d] Means within a column with different letters differ ($P < 0.05$).

3.4 Discussion

3.4.1 Forage DM yield

Soil-climatic conditions had an effect on yield and botanical composition of the binary mixtures with significant differences observed at both sites, within and across years for the different harvest dates. Forage DM yield, botanical composition and nutritive value were evaluated to rank and select binary mixtures that would meet the minimum production (2,000 kg ha^{-1}) (Alberta Agriculture and Forestry, 2008) and nutrient requirements of yearling beef cattle during summer and fall months in western Canada.

The results from this current study showed that all the binary mixtures had dry matter production well above the minimum requirement (2,000 kg ha^{-1}) for fall grazing (Alberta Agriculture and Forestry, 2008), except for GCM-RWR and WPC-RWR mixtures that failed to meet the minimum requirement for biomass production in both years. The current study produced more biomass compared to the minimum biomass requirement (2,000 kg ha^{-1}) for fall grazing. This is partly due to binary mixtures which produces 100% greater yield compared to grass or legume species in monoculture (Sleugh et al., 2000).

The results of the current study showed that DM yield at AAFC Saskatoon was two-fold greater than DM yield at AAFC SCRDC which agrees with findings reported by the Saskatchewan Forage Council (2007). This may have been due to lower precipitation and drier conditions received at AAFC SCRDC compared to AAFC Saskatoon during the study years. The current study observed 15 to 22% greater yield in the July harvest compared to the September harvest date in 2017 at both sites. The current study disagreed with findings by Biligetu et al. (2014), who reported similar yield ($P > 0.05$), between August and September harvest dates.

Holt and Jefferson (1999), suggested that precipitation is the most important determinant of binary mixtures in the semiarid regions. In support of the study by Holt and Jefferson (1999), the current study had received total precipitation of 29 and 63% lower in 2017 compared to 2016 at AAFC Saskatoon and AAFC SCRDC, respectively. This explains why July harvest were 15 to 22% greater compared to September harvest date at both sites.

Nova sainfoin yielded 45-60% in mixed stands with grass species at both sites in this study disagreed with an earlier study by Acharya (2015), who reported Nova yield was 14% in mixed and 11% in monocultural stands lower than MSF under different environment (irrigated) and multiple harvests at Lethbridge, Alberta. Sainfoin produced approximately 5 to 40% lower DM yield compared to ALF in the current study depending on the cultivar seeded, growing conditions and soil-climatic zones. This agrees with findings (Saskatchewan Forage Council, 2007), that sainfoin yielded 12 to 50% lower compared to alfalfa in the Brown and Dark Brown soil zones in Saskatchewan. In the current study MSF yielded 5 to 20% lower DM yield compared to ALF which agreed with finding by Goplen et al. (1991), in western Canada. As well, the Shoshone and Delaney sainfoin cultivars produced about 10 to 30% lower DM yield compared to AC Yellowhead alfalfa.

In a 5-yr binary mixtures study conducted at Lethbridge, Alberta (Hanna et al., 1977), total yield were greater in alfalfa (cv. Ladak)-grass mixture compared to sainfoin (cv. Eski)-grass mixture, regardless of grass species, method of seeding, or harvest year. In addition, total yields of alfalfa-grass and sainfoin-grass mixtures averaged 6,466 vs. 5,288 kg ha^{-1} yr^{-1}, but the grass component yields were virtually identical (2,817 vs. 2,812 kg ha^{-1} yr^{-1}). Thus, the difference between total yields of the alfalfa-grass and sainfoin-grass mixtures was due entirely to the difference between the yields of the legumes. The current study agreed with previous study conducted by Hanna et al. (1977). This explains why higher producing legumes such as ALF, CMV, MSF and PPC (native legume) in mixtures with grass species ranked higher in yield compared to other binary mixtures at both sites.

A 7-yr study at AAFC SCRDC by Biligetu et al. (2014), reported that binary mixture of alfalfa (cv. Rangelander) and grass species (Swift Russian wildrye, Fleet meadow bromegrass etc.) produced highest DM yield ranging from 2,449 to 2,758 kg ha^{-1}, sainfoin (cv. Nova) with crested wheatgrass produced 2,061 kg ha^{-1} while cicer milkvetch (cv. Oxley I) with green needle grass produced 1,838 kg ha^{-1}. The current study at AAFC SCRDC disagreed with Biligetu et al. (2014), findings where cicer milkvetch produced the lowest yield in mixture with grass species. However, Acharya (2009), reported biomass yield of 7,192 kg ha^{-1} in a multiple harvests for AC Veldt cicer milkvetch at Lethbridge, Alberta which was 110% greater compared to the cultivar Oxley I in the Brown and Black soil zone under different environment (irrigated). The result suggests that the lowest yield of cicer milkvetch in mixtures with grass species was a result of the cultivar Oxley I seeded during the study conducted by Biligetu et al. (2014).

A 3-yr study conducted at WBDC (Lardner et al., 2013), and a study done at five Black Soil zone sites in Saskatchewan (Lardner et al., 2000), meadow (cv. Paddock) and hybrid bromegrasses (cv. AC Knowles) were found to have a high production close to 4,000 kg ha^{-1}. In the current study, the greatest DM yield was observed for HBG + legumes mixtures compared to MBG or RWR + legume mixtures which also agreed with findings by Coulman (2006) and McLeod et al. (2003), at AAFC Saskatoon and AAFC SCRDC under similar environment and management, respectively. The 11% greater DM yield of hybrid bromegrass (cv. Success) compared to meadow bromegrass (cv. Fleet) reported by Coulman (2006), at AAFC Saskatoon, and a 10-yr average yield of 3,376 kg ha^{-1} for Russian wildrye (cv. Tom) (McLeod et al., 2003), suggests why there was an observed higher mixed stand of HBG + legume relative to MBG and RWR mixed stands in the current study. In support, a study by Saskatchewan Forage Council (2007), reported biomass yield of hybrid bromegrass (2,640 vs. 6500 kg ha^{-1}), meadow bromegrass (3,431 vs. 5,306 kg ha^{-1}), and Russian wildrye (2,193 vs. 4715 kg ha^{-1}), in the Brown and Dark Brown Soil zones in Saskatchewan, respectively. This explains why the current study observed highest yield for HBG + legume mixtures at both sites.

In a 5-yr study conducted at AAFC SCRDC (Holt and Jefferson, 1999), alfalfa (cv. Rangelander) -Russian wildrye (cv. Swift) mixture produced 3,050 kg ha^{-1} in yield which was 27% lower compared to the current study. In support of the above results, the cultivars of mixed stand species seeded plays a major role in the DM yield of the stand.

The greatest DM yield of HBG relative to RWR and MBG could have influenced the PPC-HBG mixture, ranking the highest in yield whereas the WPC-RWR mixture ranked the lowest yield at AAFC SCRDC site. A study by Kusler (2009), has reported an average yield of 3,980 kg ha^{-1} for Canadian milkvetch during several harvests from June to October at AAFC SCRDC site. Although, the current study is a binary mixture, it agrees with findings by Kusler (2009), who reported greater yield of Canadian milkvetch (cv. Great Plains Ecovar) in monoculture which could be attributed to high precipitations. The lower yield of WPC + grass species agrees with findings by McGraw et al. (2004), who reported relatively lower (12 to 84%) and (74 to 91%) yield in monoculture compared to purple prairie clover harvested at early flowering and matured stage of pods under similar environment.

All grazing animals are selective in their diet (Hodgson, 1990; Vallentine, 2001). Beef cattle perform best when kept on a consistent ration with good forage quality (Collins and Fritz, 2003), which improves dry matter intake and performance. In a 2-yr study conducted at Utah

State University Pasture Facility, Utah (Cox, 2013), forage production of cool season grasses (meadow bromegrass, orchardgrass and tall fescue) was greatest in spring with some growth in the fall and dormancy exhibited in summer. This explains why the current study had higher composition of grass species in binary mixtures in the September harvest compared to the July harvest date except in 2017 at AAFC Saskatoon. The higher composition of grass species in the July harvest compared to the September harvest date in 2017 at AAFC Saskatoon in the current study agrees with findings by Ehlke and Undersander (1990) who explained that most cool-season grasses are known to grow best in the moderate temperatures of spring and fall or a cool summer. This may explain why cool-season species tended to yield better in the July harvest compared to September harvest date in 2017 due to a high precipitation in May 2017 and cooler summer.

3.4.2 Botanical Composition of Legume Grass mixtures

Among all the grass species in binary mixtures, HBG accounted for 50% or more in mixture, while MBG accounted for 20 to 60% and RWR, 10 to 65% in both the July and September harvest dates. The current study agrees with an earlier study at AAFC SCRDC (Biligetu et al., 2014), found that percentage of DM yield of rhizomatous grass species (meadow bromegrass, western wheatgrass) in mixture was significantly different (P = 0.02) compared to caespitose grass species (Russian wildrye, crested wheatgrass) in mixtures with legumes.

In the native binary mixtures, HBG, MBG and RWR accounted for approximately 100% in the July harvest. However, in the September harvest, the cool season grasses accounted for 75 to 98% yield in mixtures with the native legumes. This is because warm or native legumes are suggested to grow more rapidly in July and August when temperatures are warm (McGraw et al., 2004).

This current study furthermore, supported research by Goplen et al. (1991) and Pearen et al. (1995), that rhizomatous grass species is very competitive with sainfoin and alfalfa for sunlight and moisture thereby reducing the composition of alfalfa in mixtures. Meadow bromegrass has shorter rhizomes compared to smooth bromegrass, vegetative enlargement is limited, does not encroach rapidly on legumes hence less dominant in mixed stands (Pearen et al., 1995). AC Success hybrid bromegrass contains the smooth bromegrass cytoplasm, which makes it more “smooth-brome like” in appearance (Coulman, 2004; 2006). This may explain why MBG is less competitive compared to HBG with legumes in a mixed stand in both soil zones in Saskatchewan.

Competition in binary mixtures is also affected by defoliation frequency, seasonal growth rates and tiller characteristics of the species (Haynes, 1980). A 3-yr study conducted at four sites in the Black Soil zone in Alberta (Pearen et al., 1995), under a two-cut system, alfalfa (cv. Beaver or Peace) growth was 97 to 197% higher in mixtures with meadow bromegrass compared to smooth bromegrass (similar to HBG) which agrees with the current study (Figure 3.1 to 3.4). According to Trenbath (1974), species in mixed swards that have higher leaves in the canopy have a competitive advantage over species with shaded leaves. This may also explain why HBG is more competitive compared to MBG because HBG is taller (1 m or more) compared to meadow bromegrass (Aasen and Bjorge, 2009). In a 5-yr study conducted at Lethbridge, Alberta, an average yield of sainfoin (cv. Nova)-Russian wildrye mixtures produced 5.8 t DM ha^{-1}, while sainfoin- crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) and sainfoin- pubescent wheatgrass (*Thinopyrum intermedium* subsp. *Barbulatum* (Schur) Barkw. and D.R. Dewey) mixtures produced 5.2 t DM ha^{-1} and 4.8 t DM ha^{-1}, respectively under different environment (irrigation) and management (multiple harvests) (Goplen et al., 1991). In addition, sainfoin contributed 61 and 48% of total DM yield when it was grown in mixtures with Russian wildrye grass and crested wheatgrass, respectively. In a 5-yr study conducted (Dubbs, 1971), in central Montana found that sainfoin was less competitive with Russian wildrye than crested wheatgrass, intermediate wheatgrass, or smooth bromegrass. In addition, sainfoin contributed 36% of total yield. The proportion composition of Russian wildrye in the current study is similar to study reported by Goplen et al. (1991), however, higher than study reported by Dubbs (1971). The current study does not support the conclusion reached by Dubbs (1971), that sainfoin and Russian wildrye mixtures should be avoided. The divergence of results may be attributable in part to the cultivars seeded and more favourable moisture conditions in this current study.

This thereby agrees with the current study results that Russian wildrye is more compatible in binary mixtures than hybrid bromegrass and meadow bromegrass.

3.4.3 Nutritive Value of Binary Legumes-Grass Mixtures

Forage quality was determined for both the native and tame mixtures harvested in July and September at AAFC Saskatoon and AAFC SCRDC site. Forage quality is important to grazing livestock because livestock rely on the energy and protein provided by the plants for maintenance and growth. However, stockpiling usually relies on mature forages that do not meet the nutrient requirements of beef cattle (Barnes et al., 2003; Añez-Osuna et al., 2017). Although dietary supplementation can help meet the nutrient requirement, they also increase the production cost. All binary mixtures were found to be more nutritious and less fibrous in 2016 compared to 2017 at either site. This may be due to a cool and wet growing season for forage production in 2016 compared to warm and dry conditions in 2017 that resulted in severe drought (Tables 3.3 and 3.4). Despite the warm and dry conditions in 2017 which resulted in lower DM yield at both sites, the native binary mixtures had greater energy content and lower fibre content in 2017 compared to 2016. According to the National Academics of Sciences, Engineering and Medicine (NASEM, 2016), growing cattle with body weight ranging from 136 to 295 kg, required 7.1 to 17.9% CP and 51.0 to 75.0% total digestible nutrient. Growing steers and heifers could have higher nutritional requirements ranging from 8.7 to 19.0% for CP and 54.0 to 83.0% for total digestible nutrient (NASEM, 2016). In addition, NASEM (2016), stated that the CP and TDN requirements for mature cows and heifers in pre-calving, postpartum, lactating and pregnant, mid-gestation periods ranged from 6.2 to 12.9% and 44.9 to 64.5%, respectively. Based on NASEM (2016), beef nutrient requirement, all native binary mixtures in the current study failed to meet the lower CP values of these ranges except GCM-RWR mixture in 2016 (Table 3.10). Among the tame binary mixtures, MSF-RWR, CMV-RWR, ALF-RWR and NSF-RWR mixtures in 2016 provided enough CP to meet the requirement suggested by NASEM (2016), for mature cows and heifers in pre-calving to mid-gestation stage at AAFC SCRDC (Table 3.9). However, all binary mixtures met the lower CP requirement values ranging 6.2 to 12.9% in 2016 at AAFC Saskatoon (Table 3.8). Regardless of the study sites, RWR + legume ranked highest in meeting the CP and TDN requirement in the July and September harvests. AC Mountainview sainfoin, ALF, CMV and NSF in mixtures with grass species showed the highest potential of having the highest CP concentrations regardless of study site. Inability of the other binary mixtures to meet the CP requirement of beef cattle suggests that they are not suitable for late summer and fall grazing under rainfed farming. The reason why most binary mixtures could not meet the CP requirement in 2017 is partly due to 31 and 49% lower precipitation compared to 30 yr precipitation at AAFC Saskatoon and AAFC SCRDC sites, respectively. All binary mixtures at both sites performed similarly in TDN concentration and met the nutrient requirement ranging from 44.9 to 64.5% (NASEM, 2016). AC Success hybrid bromegrass in mixture with tame legume species ranked highest in TDN level compared to RWR and MBG mixtures in the July and September harvest at both sites. This result suggests that HBG becomes stemmier during maturity compared to RWR and MBG (Aasen and Bjorge, 2009).

Forage fibre concentrations are important to grazing livestock since they are major fraction of dry matter and are correlated with forage intake and digestibility (Collins and Fritz, 2003). However, fibre concentrations of mixtures were largely related to fibre concentrations of the grass species (Biligetu et al., 2014; McGeough et al., 2018). According to Van Soest (1994), legumes tend to have lower ADF and neutral detergent fibre NDF concentrations compared to grass species. Legume monoculture that had lower than 40.0% NDF were considered good quality while over 50.0% were considered poor quality (NASEM, 2016). In addition, NASEM (2016), reported that grass species monoculture or in mixture that had lower than 50.0% or 45.0% NDF would be considered above-average or high quality, respectively, while those having higher concentrations than 60.0% were considered low quality. This implies that any forage stands that had lower than 35.0% ADF were considered ideal quality. With reference to NASEM (2016), NDF concentration of all tame binary mixtures in the current study in 2016 were to be considered high quality at both sites. However, in 2017, some tame binary mixtures had NDF values above 60.0% thereby qualifying into low quality category at both sites. This was not different from the native binary mixtures where all mixtures had NDF higher than 60.0% in 2016 but lower than 60.0% in 2017 at AAFC SCRDC site. Despite the warm and lower precipitation in 2017 compared to 2016, the native binary mixtures had lower ADF and NDF values thereby classifying these mixtures as high quality (NASEM, 2016). The result suggests that native binary mixtures are more drought tolerant because lower fibre concentrations were observed in the 2017 compared to 2016, although CP concentration unchanged.

In a 2 to 4 yr study of 10 native grass species at five different sites in western Canada, (Jefferson et al., 2004), the values observed for IVOMD ranging from 40.8 to 55.3% were not as high as normally observed for forage crops during the growing season. However, the results of the previous study reflected the mature phenological growth stage of the forage that was harvested in September or October. At AAFC SCRDC (Biligetu et al., 2014), found values of IVOMD (43.7 to 55.9%) of mixed stands harvested in July or August harvest which was similar to an earlier study (Jefferson et al., 2004). The current study agrees with the previous studies and this is partly due to advanced growth stage of forages. In addition, Biligetu et al. (2014), reported greater IVOMD values for meadow bromegrass (cv. Fleet) and Russian wildrye (cv. Swift) but was relatively low for crested wheatgrass. In support of the previous studies, (Alberta Agriculture and Rural Development, 2008), examined stockpiled meadow bromegrass at Lacombe, Alberta and found that it had high IVOMD and maintained good mid-October digestibility of 58 percent. The current study also agrees with previous study because RWR + legume and MBG + legumes had greater IVOMD values than HBG +legume mixtures at both sites. The result suggests that MBG also maintains it leaves and quality like RWR later in the growing season better compared to many grass species.

According to NASEM (2016), beef cattle (finishing cattle to lactating and mid-gestation) requires 0.18 to 0.90% of calcium concentration. The current study had all binary mixtures meeting the Ca concentration requirement (0.21 to 1.02%) for beef cattle at both sites. Calcium concentration in this current study was an averaged 27% greater compared to Jefferson et al.

(2004), but 44% lower compared to Biligetu et al. (2014). This was because legumes have greater Ca concentrations compared to grasses (NASEM, 2016). Based on NASEM (2016), all binary mixtures met the P concentration requirement of 0.12% in 2016 and not 2017 at both sites. This is partly due to lower precipitation in 2017 compared to 2016 at both sites. According to NASEM (2016), the ideal Ca: P ratio is approximately 1.6:1 for beef cattle, with a range of 1:1 to 4:1 being acceptable. All binary mixtures meet the ideal Ca: P ratio requirements in 2016 at both sites. This implies the need to supplement P under stockpiling in 2017.

3.5 Conclusion

Regardless of the differences in soil and climatic conditions at the study sites, all binary mixtures examined provided enough biomass for late summer and fall grazing except GCM-RWR and WPC-RWR mixtures which failed to meet the minimum requirement of 2,000 kg ha^{-1}. Due to large variations in soil and climate, no binary mixtures stood out in all aspects measured. Although the RWR + legume mixtures produced lower yield compared to MBG and HBG + legume mixtures in both yrs and sites, RWR + legumes ranked highest in nutritive value meeting the nutrient requirements of beef cattle as high-quality class (NASEM, 2016). On the other hand, HBG + legume mixtures ranked highest in comparison to MBG and RWR + legume mixtures but failed the meet NASEM (2016), requirements of CP for beef cattle. AC Admiral meadow bromegrass + legume mixtures were intermediate in term of yield and nutritive value between HBG and RWR + legume mixtures at both sites. This suggests that the goal of the beef producer is paramount to the selection of species for stockpile grazing in the late summer and fall. If yield was the major goal of the producer, then HBG + ALF or CMV or MSF mixtures would be the top choice. However, if nutritive value was the goal, then legumes in mixtures with Tom Russian wildrye.

Although the native binary mixtures performed well in yield, all treatments had lower CP levels than the nutrient requirements (CP) of beef cattle except GCM-RWR mixture. The lower precipitation in 2017 compared to the 2016 had significant effect on both yield and nutritive value thereby making most binary mixtures unable to meet the nutrient requirements for beef cattle at both sites. In conclusion, most of the binary mixtures in this study would be good candidates for late summer and fall grazing except WPC-RWR mixture which failed to meet the requirement in both yield and nutritive value. The results of the study were opposite of what we had hypothesized; that forage yield and quality will be similar at both sites. The forage yield and nutritive value of binary mixtures were two-fold greater at AAFC Saskatoon site compared to AAFC SCRDC site.

The current study which was a mixed-row seeding had shown that legumes were more compatible with RWR compared to MBG or HBG at both sites. On the other hand, HBG was most competitive to legumes followed by MBG + legumes mixtures. The aggressive nature of HBG out yielded most of the legumes in mixtures which in part affected yield and quality of the mixtures since legumes have higher crude protein, calcium and greater digestibility compared to grasses. The result suggests that although yield and nutritive value differed in contrasting agro-climatic zones, they are suitable for late summer and fall grazing. However, we recommend a mixed-row seeding of legumes with RWR and not legumes with Success hybrid bromegrass.

The fact that all native binary mixtures were in the low-quality class of NASEM (2016), except GCM-RWR mixture and also most mixtures were lower than the minimum yield of 2,000 kg ha^{-1} suggests that native binary mixtures are not good option for late summer and fall grazing.

3.6 References

Aasen, A and Bjorge, M. 2009. Alberta forage manual. Alberta Agriculture and Rural Development. Edmonton, Alberta.

Acharya, S.N. 2009. Veldt cicer milkvetch. Can. J. Plant Sci. 89:511–513. http://doi.org/10.4141/CJPS08155

Acharya, S.N. 2015. AAC Mountainview sainfoin (*Onobrychis viciifoila* subsp. *Viciifolia*). Can. J. Plant Sci. 95(3): 603–607. http://doi.org/10.4141/cjps-2014-332

Albayrak, S., Türk, M., Yüksel, O. and Yilmaz, M. 2011. Forage yield and the quality of perennial legume-grass mixtures under rainfed conditions. Not. Bot. Hort. Agrobot. Cluj. 39: 114-118

Alberta Agriculture and Forestry. 2008. Agronomic Management of Stockpiled Pastures. Agdex 420/56-4. Accessed from: https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex12422.

Añez-Osuna, F., Penner, G.B., Damiran, D., Jefferson, P.G., Lardner, H.A. and McKinnon, J. 2017. Effects of alternate day supplementation at two levels of energy on forage utilization and performance of growing steers grazing stockpiled cool-season perennial grass pastures. Can. J. Anim. Sci. 97(3): 510–516.

AOAC. 2012. Official methods of analysis. 19th ed. AOAC, Gaithersburg, MD, USA.

Association of Official Analytical Chemists. 2005. Official methods of analysis of AOAC International. 18th ed. AOAC, Arlington, VA.

Barnes, R.F., Nelson, C.J., Moore, K.J., and Collins, M. 2003. Forages: the science of grassland agriculture. Vol. II, 6th ed. Blackwell Publishing, Ames, IA, USA.

Berard, N.C., Wang, Y., Wittenberg, K.M., Krause, D.O., Coulman, B.E., McAllister, T.A. and Ominski, K.H. 2011. Condensed tannin concentrations found in vegetative and mature forage legumes grown in western Canada. Can. J. Plant Sci. 91:669–675. http://doi.org/10.4141/cjps10153

Biligetu, B., Jefferson, P.G., Muri, R. and Schellenberg, M.P. 2014. Late summer forage yield, nutritive value, compatibility of warm-and cool-season grasses seeded with legumes in western Canada. Can. J. Plant Sci., 94: 1139–1148.

Burns, J.C., Pond, K.R. and Fisher, D.S. 1994. Measurement of forage intake. In Forage quality, evaluation, and utilization. G. C. Fahey, ed. ASA, CSSA, SSSA. Madison, WI.

Collins, M. and Fritz, J.O. 2003. Forage Quality Pages 363-390 in Forages: An Introduction to Grassland Agriculture, 6th ed. Vol. 1. R. F. Barnes, C. J. Nelson, M. Collins and K. J. Moore (eds.). Iowa State Press, Ames, Iowa.

Cook, W.C. and Stubbendieck, J. 1986. Range Research: Basic problems and techniques. Society for Range Manegment. Denver, Colorado.

Coulman, B. 2006. Success hybrid bromegrass. Can. J. Plant Sci. 86:745–747.

Cox, S.R. 2013. Forage yield and quality of binary grass-legume mixtures of tall fescue, orchardgrass, meadow brome, alfalfa, birdsfoot trefoil, and cicer milkvetch. MSc Thesis. Utah State University, Logan, Utah.

Cuomo, G.J., Rudstrom, M.V., Johnson, D.G., Anderson, J.E., Singh, A. Peterson, P.R. and Sheaffer, C.C. 2005. Nitrogen fertilization impacts on stand and forage mass of cool-season grass legume pastures. Forage Grazing lands doi:10.1094/FG-2005-0831-01-RS.

Dhakal, D. 2015. Forage Grass-legume Mixture for Improved Forage Yield, Forage Quality, Stand Persistence, Soil Properties, and Economics. Ph.D. Thesis Department of Plant Sciences, University of Wyoming, Laramie, Wyoming.

Dubbs, A.L. 1971. Competition between grass and legume species on dryland. Agron. J. 68: 359–362.

Ehlke, N.J. and Undersander, D.J. 1990. Cool season grass seed production. Alternative Field Crops Manual. Minnesota Extension Service.

Ferdinandez, Y.S.N. and Coulman, B.E. 2001. Nutritive values of smooth bromegrass, meadow bromegrass, and meadow x smooth bromegrass hybrids for different plant parts and growth stages. Crop Sci. 41(2): 473–478. http://doi.org/10.2135/cropsci2001.412473x

Goplen, B.P., Richards, K.W. and Moyer, J.R. 1991. Sainfoin for western Canada. Agriculture Canada Publi. 1470/E , Ottawa, Ont.

Hanna, M.R., Kozub, G.C. and Smoliak, S. 1977. Forage production of sainfoin and alfalfa on dryland in mixed and alternate row seedings with three grasses. Can J. Plant Sci. 57: 61–70.

Haynes, R.J. 1980. Competitive aspects of the grass-legume association. Adv. Agron., 33: 227–261.

Hogh-Jensen, H. and Schjoerring, J.K. 1997. Interactions between white clover and ryegrass under contrasting nitrogen availability: N2 fixation, N fertilizer recovery, N transfer and water use efficiency. Plant Soil, 197:187–199.

Holt, N. and Jefferson, P.G. 1999. Productivity and sustainability of four grazed grass - alfalfa mixtures. Can. J. Anim. Sci. 79(1): 83–89. http://doi.org/10.4141/A98-064

Holt, N.W. 1995. Effect of snow fence or trimming seed heads or stems of Russian wildrye on April soil water content, forage and beef production. Can. J. Anim. Sci. *75*: 309–314.

Hutchings, S.S. and Stewart, G. 1953. Increasing Forage Yields and Sheep Production on Intermountain Winter Ranges. USDA Cir. 925.

Iwaasa, A.D., Schellenberg, M.P. and McConkey, B. 2012. Re-establishment of native mixed grassland species into annual cropping land. Prairie Soils and Crops J.:Scientific Perspectives for Innovative Management 5: 85–95.

Jefferson, P.G., McCaughey, W.P., May, K., Woosaree, J. and McFarlane, L. 2004. Forage quality of seeded native grasses in the fall season on the Canadian Prairie Provinces. Can J. Plant Sci., 84:503–509.

Jefferson, P.G., Lawrence, T., Irvine, B.R. and Kielly, G.A. 1994. Evaluation of sainfoin-alfalfa mixturcs for forage prcduction and compatibility at a semi-arid site in southern Saskatchewan. Can. J. Plant Sci. 74: 785–791.

Kim, B.W. and Albrecht, K.A. 2011 Forage quality management of Kura clover in binary mixtures with Kentucky bluegrass, orchardgrass, or smooth bromegrass. Asian-Aust. J. Anim. Sci. 24: 344-350

Kusler, J. 2009. Comparing simple and complex native forage mixtures in southern Saskatchewan. MSc Thesis.Department of Animal and Poultry Science. University of Saskatchewan, Saskatoon, SK. University of Saskatchewan, Saskatoon, SK

Lardner, H.A., Ward, C.I., Darambazar, E., Damiran, D. 2013. Comparison of cool season perennial grasses for forage production and nutritive value, steer performance and economic analysis. Prof. Anim. Sci. 29: 403–412.

Lardner, H.A , Wright, S.B.M., Cohen, R.D.H., Curry, P and MacFarlane, L. 2000. The effect of rejuvenation of Aspen Parkland Ecoregion grass-legume pastures on dry matter yield and forage quality. Can. J. Plant Sci. 80: 781–791.

Lauriault L.M., Guldan, S.J. and Martin, C.A. 2003. Irrigated tall fescue-legume communities in the southern Rocky Mountains: years five to eight. Agron. J. 95:1497–1503.

Li, Y.G., Tanner, G. and Larkin, P. 1996. The DMACA-HCl protocol and the threshold proanthocyanidin content for bloat safety in forage legumes. J. Sci. Food Agric.70: 89–101.

McGeough, E.J., Cattani, D.J., Koscielny, Z., Hewitt, B and Ominski, K.H. 2018. Annual and perennial forages for fall/winter grazing in western Canada. Can J. Plant Sci. 98(2): 247–254.

McGraw, R.L., Shockley, F.W. Thompson, J.F. and Roberts, C.A. 2004. Evaluation of native legume species for forage yield, quality, and seed production. Native Plants. Fall 2004.

Mcleod, J.G., Jefferson, P.G., Muri, R. and, & Lawrence, T. 2003. Tom Russian wildrye. Can. J. Plant Sci. 83:789–791.

Mcleod, J.G., Muri, R., Jefferson, P.G., Bittman, S. and Mccartney, D. 2009. Yellowhead alfalfa. Can. J. Plant Sci. 89: 653–655.

Moore, J.E., Mott, G.O., Dunham, D.G. and Omer, R.W. 1972. “Large Capacity in vitro Organic Matter Digestibility Procedure.” J. Anim. Sci. 35: 23–32.

NASEM. 2016. National academics of Sciences, engineering, and medicine. Nutrient requirement of beef cattle. Eighth revised edition. Washington, DC.

Nelson, C.J., and Burns, J.C. 2006. Fifty years of grassland science leading to change. Crop Sci. 46: 2204-2217

Nyfeler, D., Huguenin-Elie, O. Suter, M. Frossard, E.. Connolly, J. and Lüscher, A. 2009. Strong mixture effects among four species in fertilized agricultural grassland led to persistent and consistent transgressive overyielding. J. Appl. Ecol., 46: 683–691.

Nyfeler D., Huguenin-Elie, O. Suter, M. Frossard, E. and A. Luscher, A. 2011. Grass-legume mixtures can yield more nitrogen than legume pure stands due to mutual stimulation of nitrogen uptake from symbiotic and nonsymbiotic sources. Agric. Ecosyst. Environ. 140 :155–163.

Ogle, D., John, L.S., Holzworth, L.K., Jensen, K. B. and USDA NRSC. 2006. Meadow Brome *Bromus biebersteinii Roem. & Schult.* http://plants.usda.gov/plantguide/pdf/pg_brbi2.pdf. Accessed 28 January 2008.

Pearen, J. R., Baron, V. S. and Cowan, I. W. 1995. Productivity and composition of bromegrass alfalfa mixtures for hay in the Aspen Parklands of western Canada. Can. J. Plant Sci. 75: 429-436

Peng, X. 2017. Potential of Stockpiled Annual and Perennial Forage Species for Fall and Winter Grazing in the Canadian Great Plains Region. MSc Thesis. Department of Plant Science. University of Saskatchewan, Saskatoon, SK.

Ribaudo, M., Livingston, M. and Williamson, J. 2012. Nitrogen management on U.S. Corn acres, 2001-10, EB-20. U.S. Dept. of Agriculture, November 2012. 6 pp. Available online: http://www.ers.usda.gov/media/947769/eb20.pdf. Accessed: January 10, 2014.

Saskatchewan Forage Council. 2007. Forage factsheet. Dryland Forage Species Adaptation CD.

Saskatchewan Soil Survey. 1990. The soils of rural municipality of Swift Current, Number 137. Saskatchewan Soil Survey Staff, University of Saskatchewan, Saskatoon, SK.

Saskatchewan Soil Survey. 1999. The soils of poplar valley rural municipality, Number 12. Saskatchewan Soil Survey Staff, University of Saskatchewan, Saskatoon, SK.

Schultz, R.D., and Stubbendieck, J. 1982. Herbage yield of fertilized cool-season grass-legume mixtures in Western Nebraska. J. Range Manage. 35: 473–476.

Sedivec, K., Tober, D., Duckwitz, W., Dewald, D., Printz, J. 2007. Grasses for the Northern Plains. Volume 1 Cool Season. North Dakota State University Extension, Fargo, ND.

Sleugh, B., Moore, K.J., George, J.R. and Brummer, E.C. 2000. Binary legume–grass mixtures improve forage yield, quality, and seasonal distribution. Agron. J. 92: 24–29.

Thompson, L. 2003. Forage production and performance of beef yearling graziing hybrid bromegrass. MSc. Thesis. Dept. of Animal and Poultry Science. University of Saskatchewan, Saskatoon, SK.

Tilley, J.M.A. and Terry, R.A. 1963. A two stage technique for the in vitro digestion of forage crops. J. Brit. Grassld. Soc. *18*: 104–111.

Trenbath, B.R. 1974. Biomass productivity of mixtures. Adv. Agron. 26: 177–210.

Troelsen, J.E. and Hanel, D.J. 1966. Ruminant digestion in vitro as affected by inoculum donor, collection day, and fermentation time. Can. J. Anim. Sci. 46: 149–156.

Vallentine, J.F. 2001. Grazing Management. 2nd edition. Academic Press.San Diego, CA. Retrieved from http://www.sciencedirect.com/science/article/B83X7-4MSSPMB-S/2/05b99c4e7ed635ec474f319de08a4480

Van Soest, P.J. 1994. Nutritional Ecology of the Ruminant. 2nd edn., Cornell University Press, Ithaca, New York.

4 Effect of Perennial Binary Mixtures on Forage Yield, Botanical Composition, Grazing Preference and Quality

4.1 Introduction

The increasing cost of commercial nitrogen (N) fertilizers, rapid urbanization and federal and provincial land policies have limited availability of public lands for summer grazing (Peel et al., 2004; Cox, 2013) and increased the need for production practices to sustain livestock production. Beef producers are constantly seeking to minimize inputs such as fertilizer applications and labor costs while maximizing forage production, quality and pasture longevity (Thompson, 2003). Increased grass production in monoculture stands can be attributed mostly to N fertilizer and is the most variable cost of pasture production (Lardner et al., 2000; Sleugh et al., 2000). A strategy to increase yield, quality and stand longevity at cost effective is to establish a perennial grass species in a mixture with one or more legumes (Sleugh et al., 2000).

According to Kopp et al. (2003), legumes are very important during the midsummer months when forage yield declines for livestock use. Alfalfa, which is commonly used in grass-legume mixtures in western Canada is more productive in the summer months (late July to early September) when grass production slows (Cox, 2013). This is because cool-season grasses are more productive in spring and fall than in summer months (Dhakal, 2015). It is well documented that the ability of alfalfa (amount of N fixed) to increase production of grasses equals that of commercial N fertilizer (Sleugh et al., 2000; Cox, 2013). Alfalfa (cv. Yellowhead) is a creeping type which produces biomass yield lower or similar to check cultivars depending on management (multiple harvests) due to slow regrowth (McLeod et al., 2009). Alfalfa can cause bloat in ruminant animals when grazed at the early stages of growth if not grazed properly (Cox, 2013).

Sainfoin (*Onobrychis viciifolia* Scop.) is a non-bloat legume which can be managed as monoculture or in grass-legume mixtures (Aasen and Bjorge, 2009). Sainfoin (cv. Mountainview) produces biomass yield of 42% greater than (Nova) (Acharya, 2015), and older cultivars and even close to some alfalfa biomass yield (Iwaasa, personal communication, 2018).

Hybrid bromegrass (*Bromus riparius* Rehm x *Bromus inermis* Leyss) is a dual-purpose forage for both hay and pasture systems, producing high first cut hay yields like smooth bromegrass and good regrowth following cutting or grazing, similar to meadow bromegrass (Aasen and Bjorge, 2009). Hybrid bromegrass (cv. Success) is similar to smooth bromegrass and produces biomass yield 5% lower than Carlton smooth bromegrass but 8% greater than yield of Fleet meadow bromegrass (Coulman, 2006). Russian wildrye (*Psathyrostachys junceus* [Fisch.] Nevski) is an excellent species palatable to all classes of livestock and retains higher protein content than most grasses after maturity (Ogle et al., 2012a). Russian wildrye (cv. Tom) produces biomass yield of 19 and 15% (AAFC SCRDC) and 16 and 22% (AAFC Saskatoon) greater than Swift and Tetracan cultivars, respectively (McLeod et al., 2003).

A major tool for producers to optimize their resources is knowing the quality of the forage (Judy, 2014). Understanding diet quality is crucial for these operations to meet animal requirements. It is therefore important to provide information to beef producers on nutrient consumption in order to understand why cattle performance improves when grazing legumes or mixtures compared to grass monoculture. Determining the quality of the nutrients that the animal actually consumes is more complicated than simply clipping a forage sample and sending it to a laboratory for forage quality analyses (Judy, 2014).

Therefore, the objectives of this study were to determine the effect of perennial binary mixtures on forage yield, botanical composition and compare nutritive value from hand plucked and clipped samples at two different ecoregions and soil zones in Saskatchewan.

4.2 Materials and Methods

4.2.1 Research Study Sites and Experimental Design

The 2-yr grazing study was conducted at 2 different sites; (i) Agriculture and Agri-Food Canada's Swift Current Research and Development Centre (SCRDC) located at Swift Current, Saskatchewan (50°16′N 107°44′W) and (ii) Western Beef Development Centre's (WBDC) Termuende Research Ranch located at Lanigan Saskatchewan (51°51′N, 105°02′W). The soil at WBDC site is classified as an Orthic Black Chernozem, Meota-Hamlin association of loamy sand to very fine sandy loam texture, on a very gently sloping topography (Saskatchewan Soil Survey, 1992) and the soil at AAFC SCRDC is classified as Orthic Brown Chernozem, Swinton association of a silt-loam texture on a gently sloping topography (Saskatchewan Soil Survey, 1990).

Over 2 yr, grazing trials were conducted from August 8 to 31, 2016 (22 d) and July 17 to August 15, 2017 (28 d) at WBDC site. At AAFC SCRDC, grazing trials commenced from August 25 to October 11, 2016 (47 d), and July 26 to August 30, 2017 (34 d).

In 2016, 64 Angus yearling heifers (364 $\pm$ 51 kg) and in 2017, 48 Angus yearling steers (338 $\pm$ 23 kg) at WBDC, and in 2016, 40 Angus yearling steers (404 $\pm$ 18 kg) and in 2017, 48 Angus yearling steers (400 $\pm$ 16 kg) at AAFC SCRDC, respectively were allocated to the study. Each yr grazing animals were stratified by initial BW and randomly allocated to 1 of 4 replicated (n=4) binary mixtures (treatments); either (i) ALF-RWR; (ii) ALF-HBG; (iii) SF-RWR; and (iv) SF-HBG mixtures.

All animals were cared for in accordance with the Canadian Council on Animal Care (CCAC) guidelines (CCAC, 2009).

4.2.2 Forage Management

Soil samples were taken at both sites in spring 2015, 2016 and 2017 to determine levels of soil N, phosphorus (P), potassium (K) and sulphur (S) levels. Based on the soil test recommendation (Appendix Tables A.1 and A.2); (i) fields at AAFC SCRDC were fertilized with 35.0 kg ha^{-1} (11:51:0) at the time of seeding while no fertilizer was applied at WBDC site. Weed control pre- and post-seeding were managed using a broad spectrum herbicide, Round-up Transorb at 3.7 L ha^{-1} and 2,4-DB at 2.4 L ha^{-1} at WBDC and Roundup Weathermax at 4.9 L ha^{-1} and Basagran Forte at 2.2 L ha^{-1} at AAFC SCRDC, respectively.

All forage binary mixture seeds were obtained from a commercial source (Crop Production Services, Inc. and now Nutrien Ag Solutions). However, HBG was from AAFC Saskatoon Research and Development Centre. Forages were seeded into annual cropped land at AAFC SCRDC May 27 to 28, 2015 and June 5 to 7, 2015 at WBDC site. All grass and legume species were seeded in the same row for the binary mixtures. In 2015, 10.7 ha at WBDC was seeded with ALF (6.7 kg ha^{-1}), SF (22.4 kg ha^{-1}), HBG (9.0 kg ha^{-1}) and RWR (5.6 kg ha^{-1}), using a 2.4 m zero till seed opener Agro Plow drill (19 mm deep back) at 15.2 cm row spacing and 1.3 cm seeding depth. At AAFC SCRDC, 12.9 ha was seeded with ALF (3.9 kg ha^{-1}), SF (11.9 kg ha^{-1}; inoculant at 5.6 kg ha^{-1}), HBG (6.7 kg ha^{-1}), RWR (4.0 kg ha^{-1}) using John Deere 1590 Double Disc Press at 30.5 cm row spacing and 1.9 cm seeding depth.

Due to poor stand establishment, ALF and SF were overseeded at 3.3 and 2.1 kg ha^{-1} respectively, at WBDC on May 29, 2016. AC Yellowhead alfalfa, SF, HBG and RWR at 1.9, 10.8, 3.9, and 3.0 kg ha^{-1} at AAFC SCRDC respectively, on June 23, 2016.

Prior to grazing the 10.7 ha site at WBDC was further sub-divided into 16, (ea. 0.7 ha) replicate paddocks, and the 12.9 ha site at AAFC SCRDC was further sub-divided into 16, (ea. 0.8 ha) replicate paddocks. For both sites, replicated paddocks were separated electric fencing.

4.2.3 Estimated Forage Yield, Botanical Composition, Grazing preference and Forage Quality

Available forage yield (kg DM ha^{-1}) pre- and post-grazing were estimated by clipping (i) twenty 0.25 m^2 quadrats at WBDC and; (ii) ten 0.25 m^2 quadrats at AAFC SCRDC in each replicate paddock to a stubble height of 2.0 centimeters. Broadleaf weeds were hand-separated and discarded at the time of clipping and were not included in available and residual forages as animals did not appear to graze these species**.** Clipped forage samples were dried at 55^{o}C for 48 h to determine forage dry matter (DM) content and further laboratory analysis at both sites.

Botanical composition was estimated by (i) using Daubenmire frame technique (Daubenmire, 1959; USDI Bureau of Land Management, 1985) at WBDC or (ii) randomly clipping ten 0.25 m^2 quadrats per paddock and hand separating the grass or legume components at AAFC SCRDC site. The forage proportions were then oven dried at 55^{o}C for 48 h and botanical composition was determined on a DM basis and reported as percentage of total.

Grazing preference of forage species was estimated using the hand plucking technique (Edlefsen et al. 1960; Willis de Vries, 1995; Bonnet et al., 2011). Assessment of grazing preference was conducted 21 d after start of grazing in 2016 and 14 d in 2017 at both study sites.

Estimation of preference was determined to simulate bite selection (preference) of grazing animals by manually collecting plant species and plant structures selected by the animals in each replicate paddock. Forage samples were then oven dried for 48 h at 55^{o}C for DM and further laboratory analysis.

4.2.4 Laboratory Analysis

Prior to laboratory analyses, all dried samples were ground to pass through a 1-mm screen using a Wiley mill (Thomas-Wiley, Philadelphia, PA) and stored until further analysis. Estimation of forage quality included crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL), *in vitro* organic matter digestibility (IVOMD), crude protein (CP), calcium (Ca), potassium (K) and phosphorus (P) for total available, grazing preference and residual forage samples. Sequential NDF and ADF were determined using ANKOM^{200} fibre analyzer (Model 200; ANKOM; Fairport, NY). Acid detergent fibre residues were used to determine ADL using the procedure as recommended by Klason technique (Van Soest, 1994). Total N concentration was determined using the micro-Kjeldahl method (AOAC, 2012), with total Kjeldahl multiplied by 6.25 to determined CP concentration. Calcium was determined using an atomic absorption spectrophotometer (PerkinElmer, Model 2380, CN, USA), while P concentration was read at 410 nm on a spectrometer (Pharmacia, LKB-Ultraspec® III, Stockholm, Sweden). Potassium (K) concentration was determined using the methodology adapted from Steckel and Flannery (1965). *In vitro* organic matter digestibility was determined according to the procedure established by Tilley and Terry (1963) as modified by Troelsen and Hanel (1966) and Moore et al. (1972).

4.2.5 Statistical Analysis

Forage production, botanical composition and quality research data were subjected to an analysis of variance (ANOVA) as a completely randomized design (CRD) with four treatments and replicates (n=4) using the SAS Mixed Model procedure (Version 9.3; SAS Inst., Inc., Cary, NC). The statistical model was:

$$Yij = \mu + \alpha j + eij$$

where yij is the dependent variable, μ is the overall mean, αj is the fixed effect of the ith treatment, and eij is the error term specific to the experimental unit (paddock) assigned to the ith treatment.

The binary mixtures (treatments) were considered as a fixed effect in the initial analysis because of the differences in edaphic and climatic conditions between the study sites. Year was considered as a random effect when determining treatment effects on yield, botanical composition and forage quality. The Kenwardroger option was used to estimate denominator degrees of freedom. Least square means were separated using Tukey's multiple range test procedure and differences were considered significant when $P < 0.05$. The data were expressed as mean $\pm$ standard error (SE).

4.3 Results

4.3.1 Climate Data

Monthly temperature (°C) and precipitations (mm) data from 2016 to 2017 and long term averages (LTA; 30 yrs) were obtained at WBDC from Watrous East and at SCRDC in Saskatchewan according to Environmental Canada's climatic data online (www.climate.weatheroffice.ec.gc.ca) located 1 km east of either study sites. In 2016, total precipitation at WBDC and SCRDC was 22 and 29% higher than the LTA, respectively. In 2017, total precipitation was 49 and 40% lower than the LTA at SCRDC and WBDC, respectively (Tables 4.1 and 4.2). The average monthly temperatures varied among yrs but followed similar patterns as the long-term averages recorded at both sites. This was particularly apparent for the months of March through to September at WBDC and SCRDC sites. The precipitation data in 2016 reflects a cool and wet season for forage production at both conditions. In contrast, 2017 was warm and dry that resulted in severe drought conditions.

Table 4.1. Monthly Average Temperature and Precipitation and Long-Term Averages at AAFC SCRDC (2015, 2016, 2017).

	Temperature				Precipitation			
	2015	2016	2017	LTA	2015	2016	2017	LTA[z]
Month	---------------^{o}C----------------				-------------------mm----------------			
January	-8.2	-8.3	-10.3	-10.9	7.9	3.1	5.6	12.4
February	-11.1	-3.1	-7.1	-8.6	12.9	2.2	14.3	9.2
March	0.9	1.4	-2.4	-2.9	8.4	6.5	6.4	15.9
April	6.1	6.4	4.4	4.9	12.4	22.0	8.6	22.6
May	10.1	12.4	12.1	10.9	2.3	129.7	16.4	47.9
June	17.1	16.6	15.2	15.5	16.1	80.4	31.1	80.9
July	19.0	17.8	20.4	18.4	96.1	119	7.5	53.3
August	18.2	16.7	18.2	17.9	49.2	45.9	24.8	47.8
September	12.6	12.2	13.4	12.8	39.0	37.1	2.5	32.5
October	7.8	4.1	4.8	5.2	33.8	72.1	51.7	20.3
November	-1.1	3.6	-4.8	-3.0	17.2	0.2	13.5	14.6
December	-6.4	-12.6	-9.9	-9.5	8.7	4.4	6.8	14.7
Total- mean	5.4	5.6	4.5	4.2	304.0	522.6	189.2	372.1

[z]LTA= Long term averages (30 yrs)

Table 4.2. Monthly Average Temperature and Precipitation and Long-Term Averages at WBDC (2015, 2016, 2017)

	Temperature				Precipitation			
	2015	2016	2017	LTA	2015	2016	2017	LTA[z]
Months	-------------------°C----------------				------------------mm-----------------			
January	-11.9	-12.8	-11.9	-12.4	7.3	12.3	6.1	13.2
February	-17.5	-7.8	-8.6	-8.2	11.1	5.0	8.6	12.9
March	-2.2	-1.9	-5.1	-3.5	4.4	20.2	3.3	14.9
April	4.9	4.0	3.9	4.0	31.5	5.3	15.5	18.9
May	10.2	13.2	11.7	12.5	3.2	42.6	18.0	42.3
June	16.7	17.2	15.6	16.4	25.7	67.5	27.1	74.1
July	18.4	18.3	18.8	18.6	87.2	183.5	6.2	63.5
August	17	16.5	16.9	16.7	49.9	46.9	18.7	52.0
September	11.6	11.9	12.5	12.2	46.8	36.8	30.2	33.0
October	6.7	2.9	4.2	3.6	38.6	42.8	76.8	21.3
November	-2.7	1.3	-8.9	-3.8	18.7	9.0	9.9	11.8
December	-9.8	-13.6	-11.0	-12.3	7.5	4.3	2.3	14.1
Total- mean	3.4	4.1	3.2	3.7	331.9	476.2	222.7	372.0

[z]LTA= Long term averages (30 yrs)

4.3.2 Estimated Forage Yield and Botanical Composition

Forage dry matter yield **(DMY)** at AAFC SCRDC and WBDC are presented in Tables 4.3 and 4.4, respectively. Forage DMY were greater (P = 0.01) for HBG + legume mixtures at WBDC than at AAFC SCRDC and similar (P > 0.05) for RWR+ legumes mixtures at both sites. At WBDC, DMY were higher in yr 1 (P = 0.05), yr 2 (P = 0.05) and across yrs (P = 0.01) compared to AAFC SCRDC site. AC Yellowhead alfalfa + AC Success hybrid bromegrass mixture and SF-HBG mixtures were higher in yield (P = 0.01) from the ALF-RWR and SF-RWR mixtures at WBDC site.

Percent botanical composition of grass species in mixture with legumes at AAFC SCRDC and WBDC are presented in Figures 4.1 and 4.2, respectively. The percent composition of grass species in the binary mixtures was higher (P = 0.03) among treatments at WBDC, ranging from 65 to 98 percent compared to SCRDC site.

Table 4.3. Dry Matter Yield of Binary Legume-Grass Mixtures at AAFC SCRDC in 2016 and 2017

Year	Treatments					
	ALF-RWR[z]	ALF-HBG	SF-HBG	SF-RWR	SEM	*P*-value
	---------------------------------kg ha^{-1}---------------------------------					
2016	4221	3969	3849	3646	609.1	0.92
2017	4059	3893	3957	3615	612.7	0.96
Mean	4140	3931	3903	3631	404.4	0.84

[z]ALF = AC Yellowhead alfalfa; HBG = AC Success hybrid bromegrass; SF = AC Mountainview sainfoin; RWR = Tom Russian wildrye;
SEM = standard error of the mean

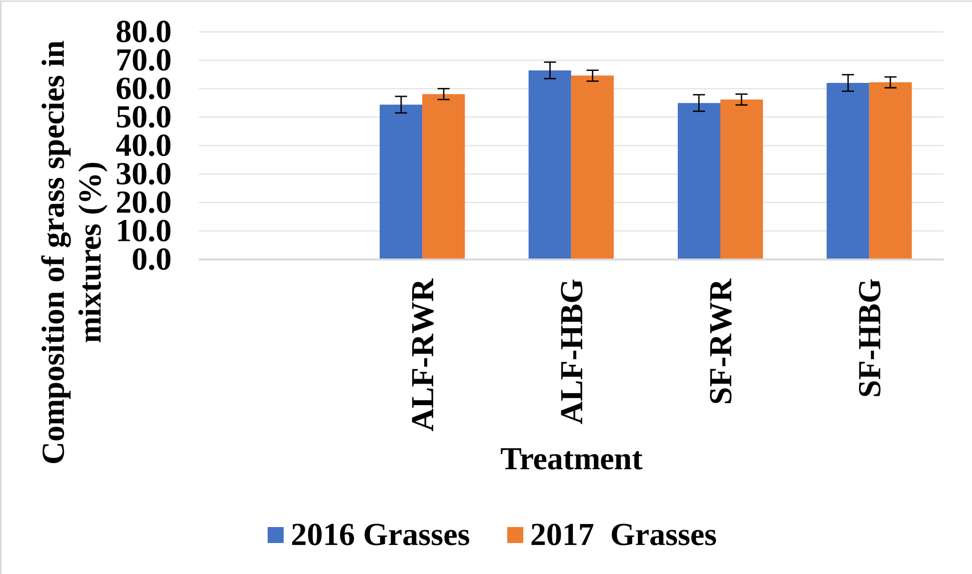


Figure 4.1. Percent Botanical Composition of Grass Species in Binary Legume Mixtures at AAFC SCRDC in 2016 and 2017.

[z]ALF = AC Yellowhead alfalfa; HBG = AC Success hybrid bromegrass; SF = AC Mountainview sainfoin; RWR = Tom Russian wildrye;

Table 4.4. Dry Matter Yield of Binary Legume-Grass Mixtures at WBDC in 2016 and 2017						
Year			Treatments			
	ALF-RWR^z	ALF-HBG	SF-HBG	SF-RWR	SEM	*P*-value
	---kg ha^{-1}--------------------------					
2016	3410b	6756a	4856b	3413b	579.4	**0.05**
2017	3966b	5045a	5365a	3844b	161.6	**0.01**
Mean	3688b	5901a	5110a	3638b	332.0	**0.01**

^{z}ALF = AC Yellowhead alfalfa; HBG = AC Success hybrid bromegrass; SF = AC Mountainview sainfoin; RWR = Tom Russian wildrye;
SEM = standard error of the mean
$^{a\text{-}b}$ Means within a row with different letters differ (P < 0.05).

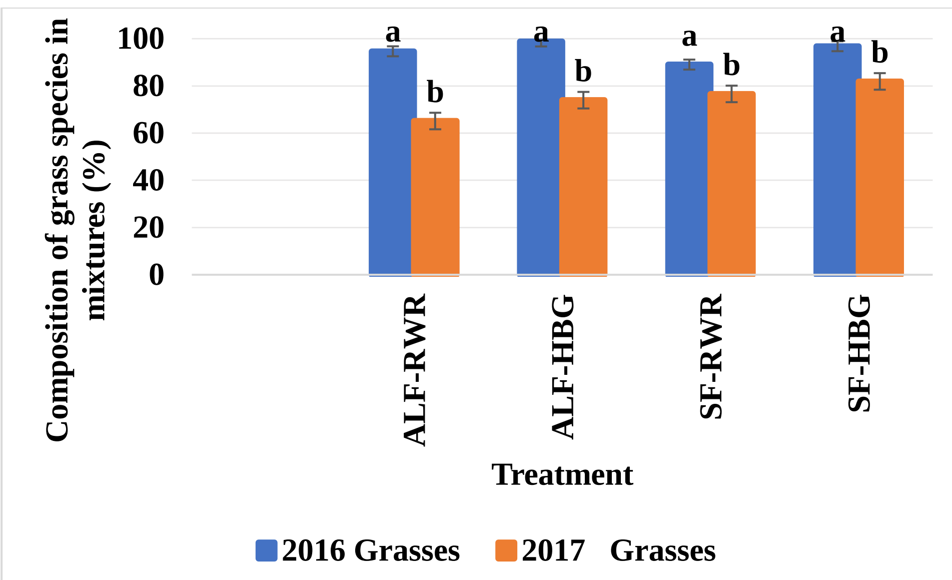


Figure 4.2. Percent Botanical Composition of Grass Species in Binary Legume Mixtures at WBDC in 2016 and 2017.

^{z}ALF = AC Yellowhead alfalfa; HBG = AC Success hybrid bromegrass; SF = AC Mountainview sainfoin; RWR = Tom Russian wildrye;
$^{a\text{-}b}$ Means with different letters differ (P < 0.05).

4.3.3 Forage Quality of Clipped and Hand Plucked Samples

Nutritive values of clipped binary mixtures, harvest date (pre- and post-grazed), and treatment by harvest date interactions at AAFC SCRDC and WBDC are presented in Tables 4.5 and 4.6, respectively. No significant treatment by harvest date interactions were observed for any forage nutritive value for the 2016 and 2017 yrs at AAFC SCRDC site. In 2016, treatment differences were observed for IVOMD and P with SF and ALF with RWR mixes being lower (P = 0.04) than ALF-HBG mixture. For harvest date, higher (P < 0.01) Ca values was observed for pre-grazing but higher (P = 0.04) K values occurred for post-grazing. In 2017, treatment differences were observed for CP and K with ALF-RWR being greater (P < 0.01) than the other treatments. For a harvest date, lower (P < 0.01) IVOMD and K values but higher (P < 0.01) ADF values occurred for post-grazing. Across 2016 and 2017 yrs, treatment by harvest date interaction was only observed (P < 0.01) for P values. Treatments differed (P < 0.01) for CP, P and K values and (P = 0.02) for ADF values. For harvest date, higher (P = 0.02) IVOMD and (P < 0.01) Ca values were observed for pre-grazing and higher (P < 0.01) ADF values occurred for post grazing.

However, at WBDC, NDF levels differed (P = 0.02), and Ca levels differed (P = 0.01) among treatment by harvest date interactions in 2016. In 2017, ADF, TDN and P levels differed (P = 0.02), and CP levels differed (P = 0.01) between treatment by harvest date interactions for forage nutritive values. In 2016, treatment differences (P < 0.01) were observed for all forage nutritive values except IVOMD values. For harvest date, all forage nutritive values differed (P < 0.01) except IVOMD and K values. In 2017, treatment differences were observed for ADF and TDN (P = 0.04), ADL (P = 0.03), CP and K (P < 0.01) and Ca (P = 0.04) values. Across 2016 and 2017 yrs, treatment by harvest date interactions were similar (*P* > 0.05) among all forage nutritive values measured. Treatment and harvest date differed among all forage nutritive value except NDF and IVOMD values, respectively.

For comparison, the nutritive value from hand plucked samples of binary mixtures at AAFC SCRDC and WBDC are presented in Tables 4.7 and 4.8, respectively. Crude protein levels was higher (*P* = 0.01) in 2016 and K (*P* = 0.04) in 2017 among treatments for hand plucked samples at AAFC SCRDC site. At WBDC, ADF (*P* = 0.02), NDF (*P* = 0.03), CP (*P* = 0.01) and TDN (*P* = 0.02) levels differed in 2016 while only K levels differed (*P* = 0.01) in 2017 among treatments for hand plucked samples.

Statistically, nutritive value in 2017 at WBDC from hand plucked samples had greater (*P* = 0.03) CP and IVOMD in the SF-RWR mixture compared to clipped samples, respectively. Lower ADF (*P* = 0.02) and greater TDN concentration (*P* = 0.04) from hand plucked samples differed for all binary mixtures at WBDC compared to clipped samples in 2017. At AAFC SCRDC, nutritive value from hand plucked samples were similar (*P* > 0.05) to clipped samples, except for IVOMD in ALF-RWR and SF-RWR mixtures in yr 1, where clipped samples were greater (*P* = 0.01), compared to hand plucked samples. Mineral content between clipped and hand plucked samples were less consistent, however the mineral content of hand plucked samples was greater (*P* < 0.05) than clipped samples at both sites (Tables 4.5 and 4.6).

Table 4.5. Nutritive Value of Clipped Samples of Binary Legume Grass Mixtures at AAFC SCRDC

Treatment[z]	OM[y]	IVOMD	ADF	NDF	ADL	CP	P	Ca	K	TDN
2016	----------	----------	----------	----------	----------%----------	----------	----------	----------	----------	----------
SF-HBG	92.6	56.0ab	37.0	51.1	7.8	7.3	0.16ab	0.62	2.66	59.5
SF-RWR	92.0	54.3b	36.3	53.8	8.6	8.6	0.14b	0.62	2.85	58.0
ALF-RWR	91.9	54.4b	35.8	54.3	7.8	8.9	0.13b	0.58	3.12	58.5
ALF-HBG	91.7	57.5a	34.6	51.3	7.1	8.5	0.18a	0.53	2.98	60.4
SEM	0.23	0.93	0.86	1.59	0.53	0.50	0.01	0.08	0.18	1.09
P-value	0.35	**0.04**	0.24	0.37	0.26	0.12	**<0.01**	0.88	0.34	0.42
Harvest date										
Pre-grazing	92.5a	56.1	35.9	51.7	7.9	8.5	0.15	0.71a	2.7b	59.4
Post-grazing	91.5b	54.9	35.9	53.6	7.8	8.2	0.15	0.46b	3.1a	58.8
SEM	0.16	0.65	0.6	1.11	0.37	0.35	0.01	0.06	0.13	0.76
P-value	**<0.01**	0.21	0.90	0.25	0.90	0.58	0.83	**<0.01**	**0.04**	0.61
Treatments x harvest date										
SEM	0.32	1.29	1.12	2.22	0.73	0.70	0.01	0.12	0.26	1.52
P-value	0.41	0.07	0.11	0.09	0.67	0.23	0.09	0.42	0.48	0.34
2017										
SF-HBG	94.6a	46.4	38.7	59.9	8.5	4.0b	0.05	0.56	1.19b	56.3
SF-RWR	93.7ab	46.5	38.4	59.3	8.9	4.7b	0.05	0.60	1.51ab	56.4
ALF-RWR	92.7b	50.3	37.0	56.3	8.1	6.3a	0.06	0.75	1.95a	57.8
ALF-HBG	94.0a	48.5	36.5	56.8	8.5	5.3ab	0.06	0.67	1.36b	58.3
SEM	0.34	1.47	0.94	2.31	0.47	0.43	0.01	0.12	1.30	1.13
P-value	**<0.01**	0.21	0.26	0.61	0.69	**<0.01**	0.27	0.65	**<0.01**	0.52
Harvest date										
Pre-grazing	93.4	49.7a	37.3	54.3b	8.2	4.9	0.06	0.72	1.79a	57.7
Post-grazing	94.0	46.2b	38.0	61.8a	8.8	5.2	0.06	0.57	1.22b	56.8
SEM	0.21	0.93	0.59	1.45	0.30	0.27	0.01	0.07	0.08	0.71
P-value	0.07	**0.02**	0.46	**<0.01**	0.21	0.53	0.49	0.19	**<0.01**	0.41

Table 4.5. Nutritive Value of Clipped Samples of Binary Legume Grass Mixtures at AAFC SCRDC (continued)										
Treatment[z]	OM[y]	IVOMD	ADF	NDF	ADL	CP	P	Ca	K	TDN
2017	--%--									
Treatments x harvest date										
SEM	0.43	1.86	1.18	2.91	0.59	0.55	0.01	0.15	0.16	1.42
P-value	0.71	0.65	0.36	0.66	0.34	0.79	0.90	0.87	0.46	0.42
Mean (2016-2017)										
SF-HBG	93.2a	51.9	36.7ab	54.4	7.9	5.8b	0.11ab	0.59	2.06b	58.4
SF-RWR	92.7ab	50.3	38.0a	56.4	8.9	6.5ab	0.09b	0.60	2.22ab	56.9
ALF-RWR	92.2b	52.2	36.8ab	55.4	7.9	7.4a	0.09b	0.63	2.58a	57.9
ALF-HBG	92.7ab	53.3	35.4b	53.3	7.8	6.8ab	0.12a	0.60	2.28ab	59.5
SEM	0.67	3.53	0.94	2.21	0.38	1.73	0.05	0.07	0.56	1.10
P-value	**<0.01**	0.09	**0.02**	0.39	0.07	**<0.01**	**<0.01**	0.97	**<0.01**	0.09
Harvest date										
Pre-grazing	92.9	52.9a	36.6	52.9b	8.1	6.7	0.10	0.72a	2.28	58.5
Post-grazing	92.5	50.9b	36.9	56.9a	8.2	6.6	0.10	0.49b	2.29	57.9
SEM	0.65	3.48	0.84	2.00	0.31	1.72	0.05	0.04	0.56	0.98
P-value	0.09	**0.02**	0.65	**<0.01**	0.69	0.89	0.99	**<0.01**	0.96	0.42
Treatments x harvest date										
SEM	0.70	3.63	1.10	2.55	0.49	1.77	0.05	0.09	0.57	1.30
P-value	0.46	0.37	0.39	0.36	0.91	0.47	**<0.01**	0.63	0.71	0.63

[z]ALF = AC Yellowhead alfalfa; HBG = AC Success hybrid bromegrass; SF = AC Mountainview sainfoin; RWR = Tom Russian wildrye;

[y]OM = organic matter; IVOMD = *in vitro* organic matter digestibility; ADF = acid detergent fibre; NDF = neutral detergent fibre; ADL = acid detergent lignin; CP = crude protein; P = phosphorus; Ca = calcium, K = potassium; TDN = total digestible nutrient; SEM = standard error of the mean

[a-b] Means within a column with different letters differ ($P < 0.05$)

Table 4.6. Nutritive Value of Clipped Samples of Binary Legume Grass Mixtures at WBDC										
Treatment[z]	OM[y]	IVOMD	ADF	NDF	ADL	CP	P	Ca	K	TDN
2016	--				-%-					--
SF-HBG	93.8	50.9	47.2a	69.0a	8.9b	5.7d	0.11c	0.28c	1.42b	47.3c
SF-RWR	92.4	53.4	43.9b	64.5b	9.7ab	10.5b	0.21a	0.54b	2.51a	50.6b
ALF-HBG	91.6	53.9	46.8a	67.3a	8.7b	8.2c	0.16b	0.39c	1.69b	47.7c
ALF-RWR	93.2	54.5	40.9c	61.8c	11.0a	12.7a	0.21a	0.69a	2.46a	53.7a
SEM	5.86	3.57	0.52	0.66	0.48	0.51	0.01	0.04	0.13	0.54
P-value	0.42	0.18	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**
Harvest date										
Pre-grazing	91.5	51.5	41.9b	60.2b	9.1	10.2a	0.19a	0.61a	1.95a	52.6a
Post-grazing	92.9	49.9	47.5a	71.1a	10	8.3b	0.16b	0.35b	2.09a	46.9b
SEM	4.14	2.53	0.37	0.47	0.34	0.36	0.01	0.026	0.09	0.38
P-value	0.36	0.66	**<0.01**	**<0.01**	0.08	**<0.01**	**<0.01**	**<0.01**	0.28	**<0.01**
Treatments x harvest date										
SEM	8.29	5.05	0.74	0.93	0.69	0.72	0.01	0.05	0.19	0.77
P-value	0.41	0.46	0.14	**0.02**	0.79	0.13	0.58	**<0.01**	0.99	0.14
2017										
SF-HBG	94.4a	50.8	42.5b	66.0	8.9ab	4.5b	0.10	0.35ab	1.36b	51.6ab
SF-RWR	92.1b	51.2	43.4ab	67.0	10.1ab	6.3a	0.09	0.40ab	2.14a	51.1ab
ALF-HBG	94.5a	51.1	42.7b	67.2	8.4b	4.1b	0.09	0.29b	1.32b	51.8a
ALF-RWR	92.1b	57.7	44.5a	68.3	10.4a	6.6a	0.10	0.45a	2.17a	50.0b
SEM	0.27	2.34	0.43	1.05	0.50	0.19	0.01	0.03	0.06	0.45
P-value	**<0.01**	0.13	**0.04**	0.53	**0.03**	**<0.01**	0.36	**0.02**	**<0.01**	**0.04**
Harvest date										
Pre-grazing	92.9b	55.4a	41.0b	64.5b	7.8b	6.0a	0.10	0.41a	2.09a	53.6a
Post-grazing	93.7a	49.9b	45.8a	69.8a	11.1a	4.7b	0.08	0.34b	1.4b	48.7b
SEM	0.19	1.66	0.31	0.74	0.35	0.13	0.01	0.03	0.04	0.32
P-value	**<0.01**	**0.03**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**0.05**	**<0.01**	**<0.01**

Table 4.6. Nutritive Value of Clipped Samples of Binary Legume Grass Mixtures at WBDC (continued)										
Treatment[z]	OM[y]	OMD	ADF	NDF	ADL	CP	P	Ca	K	TDN
2017	----------	----------	----------	----------	%	----------	----------	----------	----------	----------
Treatments x harvest date										
SEM	0.38	3.31	0.61	1.48	0.71	0.27	0.01	0.05	0.08	0.64
P-value	0.06	0.28	**0.02**	0.19	0.76	**<0.01**	**0.02**	0.70	0.82	**0.02**
Mean (2016-2017)										
SF-HBG	94.1	50.8ab	45.0a	67.5	8.9b	5.1b	0.19b	0.23b	1.38b	49.4b
SF-RWR	92.3	52.3ab	43.7ab	65.7	9.9ab	8.4a	0.32ab	0.31a	2.32a	50.8ab
ALF-HBG	88.0	47.5b	44.8a	67.2	8.5b	6.1b	0.24b	0.22b	1.51b	49.7b
ALF-RWR	92.6	56.1a	42.7b	65.0	10.7a	9.6a	0.40a	0.33a	2.31a	51.8a
SEM	2.96	2.11	0.81	1.06	0.36	1.96	0.19	0.10	0.16	0.84
P-value	0.51	**0.04**	**0.01**	0.14	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**0.01**
Harvest date										
Pre-grazing	90.2	53.4	41.5b	62.3b	8.5b	8.1a	0.35a	0.30a	2.02a	53.1a
Post-grazing	93.3	49.9	46.6a	70.4a	10.5a	6.5b	0.22b	0.25b	1.75b	47.8b
SEM	2.96	1.49	0.72	0.86	0.26	1.95	0.19	0.10	0.14	0.74
P-value	0.29	0.10	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**
Treatments x harvest date										
SEM	4.17	2.98	0.97	1.37	0.52	2.00	0.20	0.1	0.18	1.00
P-value	0.34	0.26	0.12	0.44	0.78	0.49	0.08	0.65	0.99	0.12

[z]ALF = AC Yellowhead alfalfa; HBG = AC Success hybrid bromegrass; SF = AC Mountainview sainfoin; RWR = Tom Russian wildrye;

[y]OM = organic matter; IVOMD = *in vitro* organic matter digestibility; ADF = acid detergent fibre; NDF = neutral detergent fibre; ADL = acid detergent lignin; CP = crude protein; P = phosphorus; Ca = calcium, K = potassium; TDN = total digestible nutrient; SEM = standard error of the mean

[a-b] Means within a column with different letters differ (P < 0.05)

Table 4.7. Nutritive Value of Hand-Plucked Samples from Binary Legume Grass Mixtures at AAFC SCRDC

Treatment[z]	OM[y]	IVOMD	ADF	NDF	ADL	CP	P	Ca	K	TDN
2016	---------------	---------------	---------------	---------------	---------------	%	---------------	---------------	---------------	---------------
SF-HBG	93.1	44.5	43.2	65.4	8.6	4.8b	0.11	0.28	1.10	51.4
SF-RWR	92.8	47.7	40.2	64.1	8.7	8.0a	0.11	0.44	2.10	54.5
ALF-HBG	93.3	43.8	43.5	67.2	8.7	4.7b	0.10	0.26	1.40	51.1
ALF-RWR	93.2	46.6	41.4	64.4	9.1	5.7b	0.11	0.32	1.10	53.3
SEM	0.40	2.00	2.45	2.42	1.14	0.51	0.01	0.05	0.32	2.54
P-value	0.84	0.52	0.75	0.81	0.99	**<0.01**	0.78	0.10	0.15	0.75
2017										
SF-HBG	95.2	43.1	40.3	66.1	9.4	3.8	0.05	0.42	0.86b	54.4
SF-RWR	94.0	45.4	37.7	62.9	8.6	5.0	0.06	0.49	1.33ab	57.1
ALF-HBG	94.2	47.2	36.5	59.3	8.7	5.5	0.06	0.66	0.93ab	58.2
ALF-- RWR	92.8	49.2	37.4	58.9	8.6	6.4	0.06	0.70	1.76a	57.3
SEM	0.59	2.36	1.46	3.08	0.68	0.80	0.01	0.17	0.21	1.51
P-value	0.08	0.34	0.34	0.36	0.83	0.18	0.26	0.59	**0.04**	0.34
Mean (2016-2017)										
SF-HBG	94.1	43.8	41.7	65.7	9.0	4.3b	0.08	0.35	0.98	52.9
SF-RWR	93.4	46.5	38.9	63.5	8.7	6.5a	0.08	0.46	1.72	55.8
ALF-HBG	93.7	45.5	40.0	63.2	8.7	5.1ab	0.08	0.46	1.16	54.7
ALF-RWR	93.0	47.9	39.4	61.7	8.8	6.1ab	0.08	0.51	1.43	55.3
SEM	0.59	0.51	2.36	2.41	0.62	0.55	0.02	0.62	0.21	2.44
P-value	0.19	0.29	0.51	0.55	0.98	**0.03**	0.88	0.59	0.09	0.51

[z]ALF = AC Yellowhead alfalfa; HBG = AC Success hybrid bromegrass; SF = AC Mountainview sainfoin; RWR = Tom Russian wildrye;

[y]OM = organic matter; IVOMD = *in vitro* organic matter digestibility; ADF = acid detergent fibre; NDF = neutral detergent fibre; ADL = acid detergent lignin; CP = crude protein; P = phosphorus; Ca = calcium, K = potassium; TDN = total digestible nutrient; SEM = standard error of the mean

[a-b] Means within a column with different letters differ (P < 0.05)

Table 4.8. Nutritive Value of Hand Plucked Samples from Binary Legume-Grass Mixtures at WBDC										
Treatment[z]	OM[y]	IVOMD	ADF	NDF	ADL	CP	P	Ca	K	TDN
2016	--				-%-					--
ALF-HBG	92.7a	52.4	43.9a	67.9ab	9.2	8.9b	0.19b	0.33	1.79b	50.7b
ALF-RWR	91.9ab	54.2	43.4ab	68.3a	8.0	10.8ab	0.18b	0.41	2.76a	51.2ab
SF-RWR	92.7a	53.9	41.3ab	67.2ab	8.7	10.5b	0.2b	0.37	2.93a	53.4ab
SF-HBG	91.3b	57.7	40b	63.7b	9.7	13.2a	0.29a	0.37	2.90a	54.7a
SEM	0.33	1.31	0.82	1.05	0.4	0.64	0.02	0.03	0.13	0.85
P-value	**0.03**	0.08	**0.02**	**0.03**	0.06	**<0.01**	**0.01**	0.48	**<0.01**	**0.02**
2017										
ALF-HBG	93.0	54.3	36.6	60.0	8.7	6.4	0.10	0.45	1.38b	58.2
ALF-RWR	92.0	55.5	39.0	63.0	9.3	7.9	0.10	0.52	2.24a	55.7
SF-RWR	92.1	54.2	38.2	65.4	9.0	7.9	0.10	0.44	2.43a	56.5
SF-HBG	92.8	53.9	35.8	60.0	10.2	6.6	0.11	0.42	1.37b	59.0
SEM	0.52	1.15	1.23	2.02	0.76	0.66	0.01	0.08	0.14	1.27
P-value	0.42	0.78	0.30	0.23	0.59	0.28	0.88	0.84	**<0.01**	0.30
Mean (2016-2017)										
ALF-HBG	92.9	53.3	40.2	64.0ab	9.0	7.7b	0.15b	0.39	1.58c	54.4ab
ALF-RWR	91.9	54.9	41.2	65.6ab	8.7	9.4ab	0.14b	0.46	2.50ab	53.4b
SF-RWR	92.4	54.0	39.7	66.3a	8.8	9.2ab	0.15ab	0.41	2.68a	54.9ab
SF-HBG	92.0	55.8	37.9	61.9b	9.9	9.9a	0.20a	0.40	2.13b	56.8a
SEM	0.33	0.91	1.17	2.56	0.42	1.89	0.06	0.06	0.38	2.54
P-value	0.21	0.28	0.27	**0.05**	0.17	**0.04**	**0.02**	0.61	**<0.01**	**0.04**

[z]ALF = AC Yellowhead alfalfa; HBG = AC Success hybrid bromegrass; SF = AC Mountainview sainfoin; RWR = Tom Russian wildrye;

[y]OM = organic matter; IVOMD = *in vitro* organic matter digestibility; ADF = acid detergent fibre; NDF = neutral detergent fibre; ADL = acid detergent lignin; CP = crude protein; P = phosphorus; Ca = calcium, K = potassium; TDN = total digestible nutrient; SEM = standard error of the mean

[a-b] Means within a column with different letters differ ($P < 0.05$)

4.4 Discussion

4.4.1 Estimated Forage Biomass Yield

Forage DM yield (DMY) was estimated to determine which binary mixture may be better suited for grazing in summer and fall months at each site. Although Russian wildrye and hybrid bromegrass are well adapted to the Brown and Black or Dark Brown soil zones (Saskatchewan Forage Council, 2007; Aasen and Bjorge, 2009), respectively, both grass species in mixture with sainfoin and alfalfa provided sufficient biomass to meet the minimum requirement (2,000 kg ha^{-1}) for fall grazing (Alberta Agriculture and Forestry, 2008). In the current study all of the binary mixtures produced enough biomass to exceed the minimum pasture requirement for fall grazing and ranged from 3,631 to 4,140 kg per ha at AAFC SCRDC (Table 4.3) and from 3,638 to 5,901 kg per ha at WBDC (Table 4.4). The biomass yield performance observed is partly due to binary mixtures which produce 100% greater yield compared to grass or legume species in monoculture (Sleugh et al., 2000). In support, Campbell (1963), had reported increase forage production from 841 to 1,295 kg ha^{-1} when alfalfa was added to grass only pastures at Swift Current, Saskatchewan. Furthermore, Pearen et al. (1995), had also reported 17 and 51% increase forage production when alfalfa was added to grass only pastures at Lacombe, and Bluffton and Vegreville in Alberta, respectively.

The current study also agrees with the findings of Mcleod et al. (2003), Saskatchewan Forage Council (2007) and Aasen and Bjorge (2009), that Russian wildrye is well adapted to the Brown soil zone and is also recognized as very drought tolerant with a rooting system that extends horizontally and allows moisture to be drawn up from a distance to 1.2 to 1.5 meters (Iwaasa, personal communication, 2018). Results found that RWR in mixture with either ALF or

SF produced up to 11% greater yield at AAFC SCRDC compared to the WBDC site. The biomass yield of SF-RWR and ALF-RWR mixtures increased 11 and 13%, respectively at WBDC in 2017 despite warm and dry weather. This supports earlier work by Mcleod et al. (2003) who reported that RWR grows better in a drier or drought evironment. In addition, the current study results also agree with findings of Saskatchewan Forage Council (2007) and Aasen and Bjorge (2009), that hybrid bromegrass is well adapted to the Black or Dark Brown soil zones. This was observed in the current study, where HBG in mixtures with either ALF or SF produced 24 to 33% greater yield at WBDC compared to AAFC SCRDC site.

In a 5-yr study managing binary mixtures conducted at Swift Current, Saskatchewan (Holt and Jefferson, 1999), there were no reported differences in the average forage yield among the four grass species in mixtures with alfalfa. However, the authors found yearly differences in forage yield among binary mixtures. The authors explained that annual variation in forage yield was related to precipitation, and further suggested that precipitation is the most important determinant of grass + alfalfa yield in the semiarid climate. The current study agrees with the findings by Holt and Jefferson (1999), where no significant differences were observed for average yields among binary mixtures over the 2- yr study at AAFC SCRDC site. However, at the WBDC site, there were observed differences ($P < 0.05$) among binary mixtures within and across both yrs of the study. This could be attributed to total precipitation (Holt and Jefferson, 1999), and available soil water during the growing season (Willms and Jefferson, 1993). The current study also observed on average, a 12 % lower DMY at AAFC SCRDC and 6% greater DMY at WBDC site compared to the yield of binary mixtures reported by Holt and Jefferson (1999).

A 7-yr binary mixture (8 grass species in mixtures with either sainfoin, alfalfa or cicer milkvetch) study at AAFC SCRDC (Biligetu et al., 2014), found differences (*P* < 0.01) in DMY between binary mixtures ranging from 1,861 to 2,758 kg ha^{-1}. The current study results differ with an earlier study by Biligetu and colleagues at AAFC SCRDC site, but agree with the biomass DMY of binary mixtures at WBDC site. The current study observed an average of 41 and 52% greater DMY of binary mixtures at AAFC SCRDC and WBDC, respectively, in contrast to the study by Biligetu et al. (2014). This suggests that the cultivar (variety) of species seeded also may play a role in producing greater or lower forage production. In addition, there was on average 18% greater DMY of binary mixtures at WBDC compared to the AAFC SCRDC site. This also agrees with findings by the Saskatchewan Forage Council (2007) and Aasen and Bjorge (2009), of higher forage yields for Black verses Brown soil zones in Saskatchewan and Alberta, respectively. The authors explained that variations in soil and climatic conditions were responsible for yields in the Black soil zone to be greater than the Brown soil zone. Iwaasa et al. (2008), in a 3-yr study at AAFC SCRDC reported average forage biomass production of alfalfa (cv. Spredor) + grass vs. sainfoin (cv. Nova) pastures was 4,639 vs. 3,929 kg ha^{-1}, respectively. These results reported by Iwaasa et al. (2008) are similar to the current study.

Yellowhead Alfalfa in mixture with RWR or HBG had greater DMY compared to SF in mixture with either RWR or HBG at both sites (Tables 4.4 and 4.5). The current study results agree with studies by Hanna et al. (1977) and Biligetu et al. (2014), who found on average 21% greater yield for alfalfa + grass mixtures compared to sainfoin + grass mixtures at Lethbridge, Alberta and AAFC SCRDC, respectively. In support of the current study, Goplen et al. (1991) found that sainfoin (cv. Nova) produced approximately 5 to 20% lower DMY compared to alfalfa in western Canada which also agrees with the current study at both sites. In contrast, Acharya (2015), reported that SF produced 42% greater yield than older cultivars of sainfoin and even close to some alfalfa biomass yield (Iwaasa, personal communication, 2018), which was not observed in this current study. This explains why SF in mixtures with RWR or HBG produced 12 to 13% lower yield compared to ALF in mixtures with RWR or HBG at both sites in the current study.

4.4.2 Botanical Composition of Legume Grass Mixtures

Percent botanical composition of RWR and HBG in mixtures with SF and ALF decreased (P = 0.03) among binary mixtures in 2017 at WBDC site. This suggests that SF and ALF show their potential yield later in the growing season as compared to RWR and Success hybrid bromegrass. A 4-yr study to determine forage yield of simple and complex legume-grass mixtures under two management strategies at Melfort, Saskatchewan (Foster et al., 2013), found similar results compared to the current study results at WBDC site. The authors reported that grasses were the main components of alfalfa (cv. AC Longview)-grass mixtures, with 69 to 91% grass and 9 to 31% alfalfa in yr 1. However, in the last yr, the grass component had declined in alfalfa-grass mixtures to 22 to 60% while alfalfa component had increased to 40 to 61 percent. The authors explained that increase in the proportion of alfalfa and consequent decrease in the proportion of the grass component in the simple and complex grass-alfalfa plots could have been due to an inadequate supply of soil N for the grass component in the mixtures after the second production year. In addition, a 3-yr study evaluating two perennial forage system at WBDC (Kulathunga et al., 2016), found similar results compared to the current study results at WBDC site. The authors reported that meadow bromegrass (80.3 vs. 77.7%) was the main components of alfalfa (cv. Algonquin) + meadow bromegrass mixtures in grazed stockpiled and round bale hay fed in drylot pens. These results suggest that grass species grow better in the Black soil zone in Saskatchewan compared to legumes.

.AC Mountainview sainfoin and ALF in mixtures with RWR was up to 7% greater compared with SF and ALF in mixtures with HBG at WBDC site. The current study disagrees with an earlier study by Goplen et al. (1991), that sainfoin (cv. Nova) is more compatible with Russian wildrye in mixtures compared to pubescent wheatgrass or crested wheatgrass. A 7-yr study of four perennial grass (Russian wildrye, bromegrass) + alfalfa (cv. Ladak) mixtures at Swift Current, Bracken and Tugaske, Saskatchewan during successive drought yrs (Kilcher and Heinrichs, 1966), found that Russian wildrye and bromegrasses were the two grass species which reduced the alfalfa component the most. The authors explained that Russian wildrye is a strong competitor for moisture from early spring throughout the growing season which depletes limited soil moisture in late April and early May before temperatures are sufficiently high to start alfalfa growth. This may explain why RWR had similar percent composition with HBG in mixtures with SF and ALF in 2016 and 2017 at WBDC despite being caespitose grass.

Although SF and ALF competed in mixtures with RWR and HBG at both study sites, contributions to total yield of SF and ALF at WBDC was 55 to 85% lower compared to AAFC SCRDC site. This is in support with an earlier study that grass species grow better in moist environment while deep rooted legumes thrive in dry environment (Haynes, 1980). The author concluded that competition and botanical composition differ in contrasting agro-climatic zones.

In a 3-yr study conducted at four sites in the Aspen Parkland of western Canada (Pearen et al., 1995), under a two-cut system, alfalfa (cv. Beaver or Peace) growth was 97 to 197% higher in mixtures with meadow bromegrass compared to smooth bromegrass which agrees with the current study that alfalfa produces greater yield in mixtures with grass species. According to Trenbath (1974), species in mixed swards that have higher leaves in the canopy have a competitive advantage over species with shaded leaves. This may explain why HBG is more competitive in mixture with SF and ALF compared to RWR in mixture with SF and ALF because hybrid bromegrass is taller (1 m or more) compared to meadow bromegrass or Russian wildrye (Aasen and Bjorge, 2009) thereby depriving these legumes of sufficient sunlight for growth (Goplen et al. 1991).

In a 5-yr study conducted at Lethbridge, Alberta (Goplen et al., 1991), sainfoin contributed 61 and 48% of total DM yield when it was grown in mixtures with Russian wildrye grass and crested wheatgrass, respectively. A 5-yr study conducted in central Montana (Dubbs, 1971), found that sainfoin was less competitive with Russian wildrye than crested wheatgrass, intermediate wheatgrass, or smooth bromegrass. In addition, sainfoin contributed 36% of total yield. The 43 to 45% yield contributed by SF in mixture with RWR in the current study at AAFC SCRDC site is similar to a study reported by Goplen et al. (1991), however, higher than study reported by Dubbs (1971).

These results agree with the current study in that RWR is more compatible in binary mixtures with SF or ALF compared with hybrid bromegrass in mixtures with SF or ALF at both sites.

4.4.3 Forage Nutritive Value of Clipped Samples of Binary Mixtures

Knowing the nutritive value of binary mixtures is necessary for matching the requirements of the grazing animal to the available nutrients. In all binary mixtures, CP and IVOMD decreased, and NDF, ADF and ADL increased as the grazing season progressed at both sites. This agrees with a study by McGeough et al. (2018), who reported similar results in perennial forages reporting decreases in leaf to stem ratio as a result of plant maturity. In addition, these results are similar to an earlier study which reported forage nutritive value for meadow bromegrass, smooth bromegrass and three cultivars of hybrid bromegrass at three stages of plant maturity; vegetative, heading and anthesis (Ferdinandez and Coulman, 2001). In support of the current study (Collins and Fritz 2003), found that with advancing plant maturity, changes occur to chemical composition of plants parts and within the sward structure of grass pastures, causing the nutritive value to decrease. In this current study, CP concentration, IVOMD and fibre concentrations tended to be more favorable in 2016 compared to 2017 at AAFC SCRDC while only IVOMD and CP concentrations tended to be more favorable in 2016 compared to 2017 at WBDC site. This is likely due to 53 and 64% lower precipitation in 2017 compared to 2016 at WBDC and AAFC SCRDC, respectively. According to Saskatchewan Forage Council (2007), sainfoin on average has 3% lower CP and 8% lower digestibility compared to alfalfa in all soil zones in Saskatchewan. This explains why SF mixtures with RWR and HBG had lower CP and IVOMD compared to ALF in mixtures with RWR and HBG at both sites.

According to National Academics of Sciences, Engineering and Medicine (NASEM), (2016), grazing animals have different nutritional requirements based on their stage of production. Mature cows and heifers required at least 6.2% CP, 7 months post-calving and up to 12.9% in the postpartum stage. During the mid-gestation period, the CP requirement is lower ranging from 6.5 to 8.9% (NASEM, 2016). In addition, growing steers and heifers could have higher nutritional requirements ranging from 8.7 to 19.0% for CP and 54.0 to 83.0% for TDN (NASEM, 2016). Growing cattle with body weights ranging from 136 to 295 kg require 7.1 to 17.9% CP and 51.0 to 75.0% total digestible nutrients in their diet (NASEM, 2016). All binary mixtures met the minimum TDN requirement for mature cows and heifers in pre-calving, postpartum, lactating and pregnant, mid-gestation periods ranging from 44.9 to 64.5% (NASEM, 2016). At AAFC SCRDC, all binary mixtures met the TDN requirement for all stages of production including growing steers and heifers, and pre-calving, postpartum, lactating and pregnant, mid-gestation periods in both yrs. According to Collins and Fritz (2003), forage ADF level is believed to be associated with forage digestibility and is used to calculate total digestible nutrient values. Acid detergent fibre levels averaged 16% higher among binary mixtures at WBDC compared to AAFC SCRDC, resulting in lower calculated TDN values for forages at WBDC site.

Based on NASEM (2016), all binary mixtures met the CP requirement for all stages of production for beef cattle except SF-HBG mixture in 2016 at WBDC site. In 2017, at WBDC, however, SF-HBG and ALF-HBG mixtures failed to meet the minimum CP requirements for all stages of production for beef cattle. At AAFC SCRDC however, all binary mixtures met the minimum CP requirements for mature cows and heifers and cows in mid-gestation periods except SF-HBG mixture which failed to meet the minimum CP requirement of all stages of production for beef cattle in 2016. In 2017, at AAFC SCRDC all binary mixtures failed to meet the minimum CP requirement for beef cattle at any stage of production except ALF-RWR mixture which met the minimum CP requirement for mature cows and heifers. The inability of all binary mixtures to meet the minimum CP requirements for beef cattle at all stages of growth in 2017 at both sites suggests that precipitation could play a major role in the nutritive value or quality of forages. Crude protein values in the current study in 2016 at both sites are similar to an earlier study at Saskatoon (Peng, 2017), which reported protein values for alfalfa, sainfoin and cicer milkvetch in mixtures with eight grasses including Russian wildrye (Biligetu et al., 2014). Russian wildrye in mixture with either SF or ALF in the current study, averaged 9.0 and 6.5% CP at WBDC and AAFC SCRDC, respectively. This suggests that RWR was able to maintain its protein level later in the growing season which supports an earlier study by Ogle et al. (2012b).

All binary mixtures at WBDC, averaged 16 and 18% greater ADF and NDF content compared to binary mixtures at AAFC SCRDC site. Previous binary mixture studies at AAFC SCRDC reported similar ADF and NDF values (Biligetu et al., 2014). This may be because the composition of RWR and HBG in mixture with SF or ALF was 31% greater at WBDC compared to AAFC SCRDC (Figures 4.1 and 4.2). In addition, the current study supported work by Biligetu et al. (2014), that fibre levels of mixtures are largely related to fibre concentrations of the grass species.

According to NASEM (2016), monoculture grass species or in mixture with less than 50 or 45% NDF would be considered above-average or high-quality forage. While forages having greater than 60.0% NDF are considered low quality. This implies that forage stands with lower than 35% ADF may be considered ideal quality for grazing. Based on NASEM (2016), the NDF level of all binary mixtures both in and across yrs at WBDC and AAFC SCRDC, would be considered moderate to high quality forage. However, the ADF content of all binary mixtures at both sites is considered below the ideal quality (NASEM, 2016). The current study results agree with studies by Collins and Fritz (2003) and Jefferson et al. (2004), who reported that changes occur to the chemical composition of plant parts and within swards structure causing nutritive value to decrease as plant advances in maturity.

In vitro organic matter digestibility values observed in the current study at both sites were similar among binary mixtures. This result suggests that the presence of SF and ALF in mixtures with HBG and RWR may have masked any differences among binary mixtures at both sites. A 2-yr study at WBDC (Ward, 2009), found IVOMD averaged 67.1 and 54.4% for hybrid bromegrass in spring and late summer grazing, respectively. *In vitro* organic matter digestibility values by Ward (2009), during late summer grazing agrees with the current study results. However, spring forage IVOMD reported by Ward (2009), was 20 to 30% greater compared to the current study. These results suggest that as plants mature and sward height increases, ADF and NDF increases causing digestibility of plants to decline (Hodgson, 1990; McGeough et al., 2018).

Binary mixtures in the current study had Ca concentrations ranging from 0.28 to 0.69% and 0.56 to 0.75% at WBDC and AAFC SCRDC, respectively. Binary mixtures in 2016 and 2017 and both sites met the minimum Ca requirements for beef cattle (backgrounding cattle to lactating and mid-gestation) of 0.18 to 0.90% in dietary dry matter. Forage Ca concentration in the current study at WBDC and AAFC SCRDC were 8 and 32% greater compared to a study by Jefferson et al. (2004), respectively. Based on NASEM (2016), all binary forage mixtures met the P requirements of a backgrounding steer at 0.12% in both yrs at WBDC and 2016 at AAFC SCRDC site. Forage P levels observed in the current study were similar to those reported by Jefferson et al. (2004), on native grass species in western Canada. Based on NASEM (2016), the ideal Ca:P ratio is approximately 1.6:1 for beef cattle, with a range of 1:1 to 4:1 being acceptable. All binary mixtures meet the ideal Ca: P ratio requirements in both yrs at WBDC but only in 2016 at AAFC SCRDC site. This suggests that P may need to be supplemented in 2017 at AAFC SCRDC when cattle grazed the binary mixtures. According to NASEM (2016), a growing steer, gestating and early lactating beef cows require 0.60 to 0.70% potassium in dietary dry matter. Potassium concentration of binary mixtures in the current study were 65 and 70% greater at WBDC and AAFC SCRDC, respectively, compared to NASEM (2016) requirements.

4.4.4 Forage Nutritive Value of Hand Pluck Samples

According to Vallentine (2001), Collins and Fritz (2003) and Jefferson et al. (2004), it is suggested that diet selection by grazing animals can result in forage quality of animal's diet becoming significantly greater compared to that measured on total sward offered for grazing. The nutritive value of hand-plucked samples at WBDC agreed with earlier studies by Vallentine (2001), Collins and Fritz (2003) and Jefferson et al. (2004). However, the quality of hand plucked samples at AAFC SCRDC is in contrast with findings by earlier authors. Although hand pluck samples of binary mixtures at WBDC were taken a day before ending the grazing trial in 2016, the nutritive value of these samples was similar to that of clipped samples harvested 3 weeks earlier. The results at both sites support previous reports that clipping does not provide an accurate estimation of digestibility or crude protein content of grazed pasture (Arnold and Dudzinski, 1978; Popp et al., 1999). Crude protein and digestibility of hand pluck samples from SF-RWR forage in this study were greater or similar among the other treatments compared to those estimated from clipped samples at WBDC site. This may be due to the preferential selection for leaf material by the grazing animal in monospecific swards; prehension from the top of the herbage canopy where the nutrient concentrations are likely to be greatest; or preferential selection for one species over another in multi-specific swards (Popp et al., 1999).

A 2-yr study by Jefferies and Rice (1969), to determine nutritive value of clipped and grazed forage samples found comparable protein values in dry years however, in years with abundant moisture clipped samples had lower nutritional quality. The authors also found that with the abundance of moisture, more forbs were available and consumed while in a vegetative stage resulting in greater protein and IVDMD levels of grazed vs. clipped samples. In support of these findings, Coleman and Sollenberger (2007), found in dry years or where grazing had already occurred, cattle would be forced to graze less desirable species resulting in lowered selectivity which is in agreement with work done previously (Jeffries and Rice, 1969). This may explain why the nutritive value of hand plucked (grazed) samples from binary mixtures were greater at WBDC while hand-plucked values were similar or lower at SCRDC compared to clipped samples.

According to Coleman and Sollenberger (2007), obtaining representative samples is a difficult task even in monocultures because animals prefer to graze regrowth to mature forage due to greater quality. The increased selectivity for leaf and live material causes a discrepancy between clipped versus a diet selected by an animal itself (hand plucked). Hence, clipped samples are not representative of the diet consumed by grazing animals (Edlefsen et al., 1960; Cook, t' Mannetje, 1978; Cook and Stubbendieck, 1986; Popp et al., 1999).

In support, an earlier study by Wallace et al. (1972), found that hand plucked samples and esophageal samples collected from fistulated steers were found to have similar nutritive and digestibility values and with no saliva contamination of the sample. The authors therefore suggested nutritive value of hand pluck sample as accurate if the operator is well trained.

In addition, a 2-yr study at Brandon, Manitoba (Popp et al., 1999), found that fistula samples had greater ($P < 0.05$) CP and IVDMD compared to clipped samples in all seasons, with the exception that CP did not differ (*P* > 0.05) on two occasions and IVDMD did not differ (*P* > 0.05) on one occasion. The authors added that differences in mineral content between clipped and esophageal samples were less consistent, but when differences occurred, the mineral contents of esophageal samples usually exceeded (*P* < 0.05) those of clipped samples (Popp et al., 1999). The findings in the current study support those reported by Popp et al. (1999), who stated that clipped samples mostly provide biased estimate of nutritive value of herbage consumed by grazing animal and should be reported with caution.

Based on NASEM (2016), the CP content of hand plucked samples (8.9 to 13.2%, in 2016) met the minimum nutrient requirements for beef cattle at all stages of production for all binary mixtures at WBDC and SF-RWR mixture (8.0 % CP) at AAFC SCRDC site. Crude protein levels of all binary mixtures at WBDC and SF-RWR mixture at AAFC SCRDC disagreed with the suggestion by McGeough et al. (2018), that stockpile grazing has traditionally been used for beef cows in mid-gestation. Crude protein levels of binary mixtures in 2017 at AAFC SCRDC failed to meet the minimum CP requirement of beef cattle at any stage of production except ALF-RWR mixture. All binary mixtures in 2016 at both sites met the minimum TDN (energy) requirements ranging from 44.9 to 64.5% for beef cows in mid gestation and all stages of production in 2017.

Acid detergent fibre and NDF concentrations of mixtures at both sites were slightly higher than the ideal quality (< 35.0% ADF and 45.0 to 50.0% NDF), respectively according to NASEM (2016). All minerals levels of binary mixtures met the minimum requirement (Ca = 0.18 to 0.90%; P =0.12% and K = 0.60 to 0.70%) according to NASEM (2016), in both yrs at WBDC and AAFC SCRDC (except P levels in 2017).

4.5 Conclusion

Adaptation of grass species in different soil and climatic zones in Saskatchewan can vary, yet all binary mixtures examined in the current study produced biomass yields greater than the minimum forage yield (2,000 kg ha^{-1}) for summer and fall grazing in western Canada. AC Success hybrid bromegrass in mixtures with either SF or ALF produced greater yields than SF-RWR and ALF-RWR mixtures at WBDC, while biomass yield of binary mixtures at AAFC SCRDC were similar. All binary mixtures appear to be good candidates for late summer and fall grazing. However, a producer whose objective is high yield may opt for HBG in mixture with SF or ALF in the Black soil zone and RWR in mixtures with SF or ALF in the Brown soil zone in Saskatchewan. On average there was 26% greater composition of grass species in mixture at WBDC compared to AAFC SCRDC site. This suggests that grass species may grow better in moist regions while legume species grow better in drier regions. Tom Russian wildrye in mixtures with SF and ALF were more compatible compared to HBG in mixtures with SF and ALF at both sites. To achieve the optimal ratio of 50:50 legumes to grass species for improved yield, forage quality and stand persistence it is not recommended to practice a mixed row seeding pattern for hybrid bromegrass in mixture with either sainfoin or alfalfa.

Tom Russian wildrye in mixtures with SF or ALF performed better in nutritive value compared to SF-HBG and ALF-HBG mixtures in both yrs at WBDC and 2017 at AAFC SCRDC site. In late summer to fall months where forage quality declines because of maturity, beef producers are seeking forages that are high in nutritive value to avoid or reduce dietary supplement costs. All binary mixtures in this study would be good candidates, the exception may be ALF which could suffer leaf loss after frost thereby reducing its quality in mixtures.

Nutritive value of hand plucked samples of binary mixtures at both sites suggest that beef cattle are selective in their diet. Hence, the quality of hand plucked samples are not similar to quality of clipped samples at AAFC SCRDC and WBDC site. Study results also suggest that the nutritive value of clipped samples may not be a true representative of the diet consumed by grazing animals. The nutrient levels of all binary forage mixtures met the minimum nutritional requirement of beef cattle in all stages of production at both sites. The exception being CP and P content of forages at AAFC SCRDC site. Biomass yield and nutritive value of clipped and hand plucked samples from binary mixtures were greater at WBDC compared to AAFC SCRDC site. In conclusion, all binary mixtures in the study would provide good late summer and fall month grazing with or without dietary supplement.

4.6 References

Aasen, A and Bjorge, M. 2009. Alberta forage manual. Alberta Agriculture and Rural Development. Edmonton, Alberta.

Acharya, S.N. 2015. AAC Mountainview sainfoin (*Onobrychis viciifoila* subsp. *Viciifolia*). Can. J. Plant Sci. 95(3): 603–607. http://doi.org/10.4141/cjps-2014-332

Alberta Agriculture and Forestry. 2008. Agronomic Management of Stockpiled Pastures. Agdex 420/56-4. Accessed from: https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex12422.

AOAC. 2012. Official methods of analysis. 19th ed. AOAC, Gaithersburg, MD, USA.

Arnold, G.W. and Dudzinski, M.L. 1978. "Ethnology of Free Ranging Domestic Animals." Elsevier, N.Y. 198 pp.

Association of Official Analytical Chemists. 2005. Official methods of analysis of AOAC International. 18th ed. AOAC, Arlington, VA.

Biligetu, B., Jefferson, P.G., Muri, R. and Schellenberg, M.P. 2014. Late summer forage yield, nutritive value, compatibility of warm-and cool-season grasses seeded with legumes in western Canada. Can. J. Plant Sci., 94: 1139–1148.

Bonnet, O., Hagenah, N., Hebbelmann, L., Meuret, M., Shrader, A. 2011. Is hand-plucking an accurate method of estimating bite mass and instantaneous intake rate of grazing herbivores? Rangeland Ecology and Management, 64:366–374.

Canadian Council on Animal Care. 2009. Guide to the care and use of experimental animals No. 1. Olfert, E. D., Cross, B. M. and Mc William, A. A., Canadian Council on Animal Care.Ottawa, ON, Canada.

Collins, M. and Fritz, J.O. 2003. Forage Quality Pages 363-390 in Forages: An Introduction to Grassland Agriculture, 6th ed. Vol. 1. R. F. Barnes, C. J. Nelson, M. Collins and K. J. Moore (eds.). Iowa State Press, Ames, Iowa.

Cook, W.C. and Stubbendieck, J. 1986. Range Research: Basic problems and techniques. Society for Range Manegment. Denver, Colorado.

Coulman, B. 2006. Success hybrid bromegrass. Can. J. Plant Sci. 86:745–747.

Cox, S.R. 2013. Forage yield and quality of binary grass-legume mixtures of tall fescue, orchardgrass, meadow brome, alfalfa, birdsfoot trefoil, and cicer milkvetch. MSc Thesis. Utah State University, Logan, Utah.

Daubenmire, R. 1959. A Canopy-coverage method of vegetational analysis. Northwest Science, 33:43–64.

Dhakal, D. 2015. Forage Grass-legume Mixture for Improved Forage Yield, Forage Quality, Stand Persistence, Soil Properties, and Economics. Ph.D. Thesis Department of Plant Sciences, University of Wyoming, Laramie, Wyoming.

Edlefsen, J.L., Cook, C.W., and Blake, J.T. 1960. Nutrient content as determined by hand-plucked and esophageal fistula samples. J. Anim. Sci. 19: 560-567

Ferdinandez, Y.S.N. and Coulman, B.E. 2001. Nutritive values of smooth bromegrass, meadow bromegrass, and meadow x smooth bromegrass hybrids for different plant parts and growth stages. Crop Sci. 41(2): 473–478. http://doi.org/10.2135/cropsci2001.412473x

Foster, A., Vera, C.L., Malhi, S.S. and Clarke, F.R. 2013. Forage yield of simple and complex grass_legume mixtures under two management strategies. Can J. Plant Sci. (94): 41–50.

Frame, J. 2005. Forage Legumes for Temperate Grasslands. Enfield, NH, USA.: FAO. Science Publishers, Inc.

Goplen, B.P., Richards, K.W. and Moyer, J.R. 1991. Sainfoin for western Canada. Agriculture Canada Publi. 1470/E , Ottawa, Ont.

Hanna, M.R., Kozub, G.C. and Smoliak, S. 1977. Forage production of sainfoin and alfalfa on dryland in mixed and alternate row seedings with three grasses. Can J. Plant Sci. 57: 61–70.

Haynes, R.J. 1980. Competitive aspects of the grass-legume association. Adv. Agron., 33: 227–261.

Hilty, J. 2007. Prairie Wildflowers of Illinois. http://www.illinoiswildflowers.info/prairie/plant_index.htm#purple_clover. Accessed 18 July 2007.

Hodgson, J. 1990. "Grazing Management: Science into Practice." John Wiley & Sons, New York.

Hogh-Jensen, H. and Schjoerring, J.K. 1997. Interactions between white clover and ryegrass under contrasting nitrogen availability: N2 fixation, N fertilizer recovery, N transfer and water use efficiency. Plant Soil, 197:187–199.

Holechek, J.J., Gomez, H., Molinar, F. and Galt, D. 1999. Grazing studies: what we've learned. Rangelands 21(2): 12–16.

Holechek, J.L., Vavra, Me and Pieper, R.D. 1981. Diet quality and performance of cattle on forest and grassland range. J. Anim. Sci. 52: 291–299.

Holt, N. and Jefferson, P.G. 1999. Productivity and sustainability of four grazed grass - alfalfa mixtures. Can. J. Anim. Sci. 79(1): 83–89. http://doi.org/10.4141/A98-064

Iwaasa, A.D. Lemke, R. and Jefferson, P.G. 2008. Carbon sequestration, methane production and nitrous oxide emission from cattle grazing native prairie. Beef Cattle Research Council Final Report 2.68, October, 2008. 63 pp.

Jasmer, G.E. and Holechek, J.L. 1984. Determining grazing intensity on rangeland. J. Soil Water Conserv. 39: 32–35.

Jefferies, N.W. and Rice, R. 1969. Nutritive value of clipped and grazed rage forage samples. J. Range. Manage. 2(3):192–195.

Jefferson, P.G., McCaughey, W.P., May, K., Woosaree, J. and McFarlane, L. 2004. Forage quality of seeded native grasses in the fall season on the Canadian Prairie Provinces. Can J. Plant Sci., 84:503–509.

Judy, J.V. 2014. Effects of stocking rate on forage nutrient composition of Nebraska sandhills upland range when grazed in early summer and the effects of grazing on Nebraska sandhills meadow forage nutrient composition. Msc. Thesis. Department of Animal Science. University of Nebraska, Lincoln, Nebraska

Kopp, J.C., McCaughey, W.P. and Wittenberg, K.M. 2003. Yield, quality and cost effectiveness of using fertilizer and/or alfalfa to improve meadow bromegrass pastures. Can. J. Anim. Sci. 83: 291–298.

Kulathunga, D.G.R.S., Penner, G.B., Schoenau, J.J., Damiran, D., Larson, K., & and Lardner, H. 2016. Effect of perennial forage system on forage characteristics, soil nutrients, cow performance, and system economics. The Prof. Animal Sci. 32: 784–797.

Lardner, H.A , Wright, S.B.M., Cohen, R.D.H., Curry, P and MacFarlane, L. 2000. The effect of rejuvenation of Aspen Parkland Ecoregion grass-legume pastures on dry matter yield and forage quality. Can. J. Plant Sci. 80: 781–791.

Lauriault L.M., Guldan, S.J. and Martin, C.A. 2003. Irrigated tall fescue-legume communities in the southern Rocky Mountains: years five to eight. Agron. J. 95:1497–1503.

McLeod, J.G., Jefferson, P.G., Muri, R. and Lawrence, T. 2003. Tom Russian wildrye. Can. J. Plant Sci. 83:789–791.

McLeod, J.G., Muri, R., Jefferson, P.G., Bittman, S. and Mccartney, D. 2009. Yellowhead alfalfa. Can. J. Plant Sci. 89: 653–655.

Moore, J.E., Mott, G.O., Dunham, D.G. and Omer, R.W. 1972. “Large Capacity in vitro Organic Matter Digestibility Procedure.” J. Anim. Sci. 35: 23–32.

Mooso, G.D. and Wedin, W.F. 1990. Yield dynamics of canopy components in alfalfa-grass mixtures. Agron. J. 82: 696–701.

Ogle, D., St. John, L., Cornwell, J., Holzworth, L., Majerus, M., Tober D., Jensen, K., Sanders, K.E. (rev) St. John. 2012a. Plant Guide for Russian Wildrye *(Psathyrostachys junceus).* USDA-Natural Resources Conservation Service, Aberdeen Plant Materials.

Pearen, J. R., Baron, V. S. and Cowan, I. W. 1995. Productivity and composition of bromegrass alfalfa mixtures for hay in the Aspen Parklands of western Canada. Can. J. Plant Sci. 75: 429-436

Peel, M.D., Asay, K.H., Johnson, D.A. and Waldron, B.L. 2004. Forage production of sainfoin across an irrigation gradient. Crop Sci. 44: 614-619

Popp, J.D, McCaughey, W.P, Thomas, L.R and Cohen, R.D. 1999. Nutrient selection by cattle from grass and grass/legume pastures. Can J. Anim. Sci. 79: 391–395.

Saskatchewan Forage Council. 2007. Forage factsheet. Dryland Forage Species Adaptation CD.

Saskatchewan Soil Survey. 1990. The soils of rural municipality of Swift Current, Number 137. Saskatchewan Soil Survey Staff, University of Saskatchewan, Saskatoon, SK.

Saskatchewan Soil Survey. 1992. The soils of prairie rose rural municipality, Number 309. Saskatchewan Soil Survey Staff, University of Saskatchewan, Saskatoon, SK.

Sleugh, B., Moore, K.J., George, J.R. and Brummer, E.C. 2000. Binary legume–grass mixtures improve forage yield, quality, and seasonal distribution. Agron. J. 92: 24–29.

Steckel, J.E. and Flannery, R.L. 1965. Automatic determination of phosphorus, potassium, calcium and magnesium in wet digestion solutions of plant tissue. Pages 83-96 in Technicon Symposium. Auto. Anal. Chem. New York.

Stubbendieck, J.L and Conard, E.C. 1989. Common legumes of the Great Plains: An Illustrated Guide. University of Nebraska Press. Lincoln, NE.

t' Mannetje, L. 1978. Measuring quantity of grassland vegetation. Pages 63-95 in 't Mannetje ed. Measurement of grassland vegetation and animal production. CAB, Farnham Royal, Bucks, England.

Thompson, L. 2003. Forage production and performance of beef yearling graziing hybrid bromegrass. MSc. Thesis. Dept. of Animal and Poultry Science. University of Saskatchewan, Saskatoon, SK.

Thonney, M.L., Duhaime, D.J., Moe, P.W. and Reid, J.T. 1979. Acid insoluble ash and permanganate lignin as indicators to determine digestibility of cattle rations. J. Anim. Sci. 49: 1112–1116.

Tilley, J.M.A. and Terry, R.A. 1963. A two stage technique for the in vitro digestion of forage crops. J. Brit. Grassld. Soc. *18*: 104–111.

Trenbath, B.R. 1974. Biomass productivity of mixtures. Adv. Agron. 26: 177–210.

Troelsen, J.E. and Hanel, D.J. 1966. Ruminant digestion in vitro as affected by inoculum donor, collection day, and fermentation time. Can. J. Anim. Sci. 46: 149–156.

USDI Bureau of Land Management. 1985. Rangeland monitoring - Trend Studies TR4400-4.

Vallentine, J.F. 2001. Grazing Management. 2nd edition. Academic Press.San Diego, CA. Retrieved from http://www.sciencedirect.com/science/article/B83X7-4MSSPMB-S/2/05b99c4e7ed635ec474f319de08a4480

Van Soest, P.J. 1994. Nutritional Ecology of the Ruminant. 2nd edn., Cornell University Press, Ithaca, New York.

Wallace, J.D., Hyder, D.N. and Van Dyne, G.M. 1972. Salivary contamination of forage selected by esophageal fistulated steers grazing sandhill grassland. J. Range Mgt. 25: 184–188.

Ward, C.I. 2009. The effect of perennial grass species on forage growth and quality, etiolated growth, animal performance and economics. MSc Thesis. University of Saskatchewan, Saskatoon, SK.

Willis de Vries, M. 1995. Estimating forage intake and quality in grazing cattle: a reconsideration of the hand-plucking method. J. Range Mgt. 48: 370–375.

Willms, W.D and Jefferson, P. 1993. Production characteristics of the mixed prairie: constraints and potential. Can J. Anim. Sci. 73: 765–778.

5 Effect of Perennial Binary Mixtures on Estimated Dry Matter Intake, Forage Utilization and Animal Performance

5.1 Introduction

Sustainable beef production in western Canada depends on pasture forages. However, in summer when temperatures are hottest, a ‘summer slump’ or period of reduced growth or grass dormancy is exhibited resulting in lower forage quality and less cattle selectivity (Judy, 2014). According to Popp et al. (2000), performance of grazing animals reflects a balance between its nutrient requirements and the nutrients it is able to consume. The author added that when herbage availability increases, intake rate also increases, even when pastures are of similar digestibility and protein content (Popp et al., 2000). It is therefore important for livestock producers to consider potential forage yield and quality, forage intake and animal performance in response to intake of available forage when selecting plant species (Holechek et al., 1981; Vallentine, 2001; Judy, 2014).

Alfalfa is one of the most productive legumes because of its superior yield, grows under a wide range of environments and is a multi-purpose crop (Campbell, 1963; Aasen and Bjorge, 2009). Alfalfa in mixture with grass species produced greater liveweight gains per animal and per hectare, and greatly reduced forage consumption per kg of liveweight gain (Campbell, 1963). The author reported average daily gain of 0.06 and 0.03/d for ewes grazing alfalfa +grass mixture and monoculture grass species at AAFC SCRDC, respectively. Limited data is available on the grazing preference and performance of steers on AC Yellowhead alfalfa pasture.

Sainfoin, a bloat free legume, has shown to produce in both dry and irrigated lands for hay or pasture (Hanna et al., 1977; Aasen and Bjorge, 2009). A study by Karnezos et al. (1994), showed that lamb production per hectare was 23% greater when grazing sainfoin + wheatgrass mixture compared to a wheatgrass monoculture. The author also found that sainfoin monoculture increased production per hectare by 25% compared to the mixture. The author suggested that weight gain in ruminants is highly correlated to proportion of legumes in grass-legume mixtures (Karnezos et al., 1994). Beef cattle grazing Mountainview sainfoin in mixtures with Beaver alfalfa or AC Blue J alfalfa produced ADG and TBP of 0.89 to 1.21 kg d^{-1} vs. 329 to 598 kg ha^{-1} and 0.79 to 1.11 kg d^{-1} vs. 143 to 277 kg ha^{-1} at Lethbridge, Alberta and AAFC SCRDC, respectively (Sottie, 2014).

Russian wildrye and hybrid bromegrass are grasses known for their yield and quality in the grazing season in the Brown, Black and Dark Brown soil zone, respectively (Aasen and Bjorge, 2009). Russian wildrye has the ability to retain higher protein content than most grass species after maturity thereby making it palatable to all classes of livestock in late summer through to winter (Ogle et al., 2012a). Thompson (2003), reported greatest beef production (160 to 185 kg ha^{-1}) for steers grazing hybrid bromegrass (cv. Knowles) pasture compared to other bromegrasses and crested wheatgrass at WBDC site. Limited or no data on grazing preference and performance is available on Success hybrid bromegrass and Tom Russian wildrye.

It is therefore important for beef producers to consider selection of forage legume varieties that are compatible with grass species for potential forage yield and quality, forage intake and persistence for livestock production. To achieve this, beef producers require in-depth insight on how new forage legumes species in mixtures with cool-season perennial grass species perform in biomass yield and quality to meet the grazing needs for sustainable beef production. In addition, beef producers also need information on animal’s intake, average daily gain (ADG), grazing days per hectare and beef production per hectare.

The objectives of this study were to evaluate estimated dry matter intake, forage utilization, animal average daily gain, animal grazing days and beef production per hectare of four legume-grass mixtures in the Brown and Black soil zones of Saskatchewan.

5.2 Materials and Methods

5.2.1 Research Study Sites and Experimental Design

The study sites and the experimental designs were described in Chapter 4.

5.2.2 Grazing Animal Management

Over 2 yr, grazing trials were conducted from August 8 to 31, 2016 (22 d) and July 17 to August 15, 2017 (28 d) at Western Beef Development Centre at Lanigan, Saskatchewan. At Swift Current Research and Development Centre of Agriculture and Agri-Food Canada in Saskatchewan, grazing trials commenced from August 25 to October 11, 2016 (47 d), and July 26 to August 30, 2017 (34 d).

Yearling Angus heifers (n = 64, BW = 364 ± 51 kg in 2016) and yearling Angus steers (n = 48, BW = 338 ± 23 kg in 2017) at WBDC and yearling Angus steers (n = 40, BW = 404 ± 18 kg in 2016, n = 48, BW = 400 ± 16 kg in 2017) at AAFC SCRDC, were allocated to the study. Each yr grazing animals were stratified based on BW and randomly allocated to 1 of 4 replicated (n=4) binary mixtures (treatments); either (i) ALF-RWR (ii) ALF-HBG (iii) SF-RWR; or (iv) SF-HBG. Each treatment (n = 4) had four replicate (n = 4) paddocks and consisted of 4 (2016) heifers, 3 (2017) steers at WBDC and either 2 to 3 (2016) or 3 (2017) at AAFC SCRDC in a continuous stocking system.

Prior to the grazing experiment, animals grazed on similar pastures for a 14 d adaptation period at both sites. All animals were cared for in accordance with the Canadian Council on Animal Care (CCAC) guidelines (CCAC, 2009).

During the grazing trial, 27 g d^{-1} per animal of cobalt iodized salt and a 1:1 range mineral [98.0% salt (minimum), 99.5% salt (maximum), 200 mg/kg I, 100 mg/kg Cu; Feed Rite, Division of Ridley, Inc.] at WBDC site. At AAFC SCRDC, 25 g d^{-1} per steer of Saltec® [90.0% salt (minimum), 93.0% salt (maximum), 15,000 mg/kg Zn, 10,000 mg/kg Mg, 5,000 mg/kg Cu, 1,600 mg/kg Fe, 200 mg/kg I, 100 mg/kg Cu; ultra TM salt: Ceres Industries]. Water was provided *ad libitum* to all paddocks in stock troughs through surface pipelines at both sites.

Average daily gain (kg d^{-1}) was calculated for each pasture (experimental unit) from the initial and final weights of animals of the grazing season. Animal grazing days (AUD ha^{-1}) was also calculated from the product of the average animal unit in each treatment and steer grazing days according to formula of Forage and Grazing Terminology Committee (1992), and Holt and Jefferson (1999). The latter was calculated from the product of the number of steers and days on the treatment, divided by the pasture size. Total beef production (kg ha^{-1}) was calculated from the product of average daily gain and animal grazing days for each experimental unit as described by Forage and Grazing Terminology Committee (1992), and Holt and Jefferson (1999).

5.2.3 Estimated Forage Utilization and Dry Matter Intake

Estimated forage utilization and dry matter intake (DMI) were determined using the Herbage Disappearance technique (Pearson, 1975). The technique was conducted by randomly clipping twenty, 0.25 m^2 quadrats at WBDC and ten 0.25 m^2 quadrats at AAFC SCRDC per paddock to a stubble height of 2 cm before and after the grazing trial. Broadleaf weeds were hand-separated and discarded at the time of clipping and were not included in available and residual forages as animals did not graze these species**.**

Estimated forage utilization and DMI were calculated using the following equations by Jasmer and Holecheck (1984) and Kelln et al. (2011):

$$\text{Forage utilization (\%)} = \frac{\text{DM available (g- 0.25 m}^2\text{) - DM residual (g- 0.25 m}^2\text{)}}{\text{DM available (g- 0.25 m}^2\text{)}}$$

$$\text{DMI (kg d}^{-1}\text{)} = \frac{\text{DM available (g- 0.25 m}^2\text{) - DM residual (g- 0.25 m}^2\text{)}}{\text{n. d}}$$

where d = the number of days the paddock will be grazed and

n = the number of animals per paddock.

5.2.4 Statistical Analysis

Grazing animal performance, estimated DMI and utilization research data were subjected to analysis of variance (ANOVA) as a randomized complete block design (RCBD) using the SAS Mixed Model procedure (Version 9.3; SAS Inst., Inc., Cary, NC). The statistical model was:

$$Yij = \mu + \rho i + \alpha j + eij$$

where Yij is the dependent variable, μ is the overall mean, ρi is the block of the ith treatment, αj is the fixed effect of the ith treatment, and eij is the error term specific to the experimental unit (paddock) assigned to the ith treatment

The binary mixtures (treatments) were considered as a fixed effect in this initial analysis because of the differences in edaphic and climatic conditions between the study sites. Year considered as random effect and the block effect was animal’s weight. The effect of treatments on average daily gain, animal grazing days, total beef production, forage utilization and dry matter intake estimations were analyzed. The Kenwardroger option was used to estimate denominator degrees of freedom. Least square means were separated using Tukey's multiple range test procedure and difference considered significant when $P < 0.05$.

5.3 Results

Effect of binary mixtures on estimated DMI, forage utilization and grazing heifer and steer performance at AAFC SCRDC and WBDC are presented in Tables 5.1.and 5.2. Steer ADGs in 2017 for SF-RWR mixture was higher ($P = 0.02$) than ALF-HBG mixture but similar to the other treatments and this was observed for the ADGs averaged over the 2 yrs at WBDC site. Steers AGD in 2017 for ALF-HBG mixture was higher ($P < 0.01$) than SF-RWR and ALF-RWR but similar to SF-HBG mixture and this was also observed for the AGDs averaged over the 2 yrs at AAFC SCRDC site. Steer TBP in 2017 for ALF-HBG mixture was higher ($P = 0.01$) than SF-RWR and ALF-RWR mixtures but similar to SF-HBG mixture at AAFC SCRDC site. Steers TBP in 2016 and 2017 for ALF-HBG mixture was higher ($P = 0.05$) than SF-RWR mixtures but similar to ALF-RWR and SF-HBG mixtures at AAFC SCRDC site. Percent forage utilization over 2016 and 2017 for SF-RWR mixture was higher ($P = 0.05$) than SF-HBG mixture but similar to ALF-RWR and ALF-HBG mixtures.

Table 5.1. Effect of Binary Mixtures on Estimated Dry Matter Intake, Forage Utilization and Grazing Steer Performance in 2016 and 2017 at AAFC SCRDC

	Treatments					
	ALF-RWR[z]	ALF-HBG	SF-HBG	SF-RWR	SEM	*P*-value
2016						
ADG[y] (kg d^{-1})	0.79	0.82	0.71	0.82	0.08	0.72
AGD (AUD ha^{-1})	132	140	137	123	14.49	0.85
TBP (kg ha^{-1})	106	112	100	101	13.99	0.92
DMI (kg d^{-1})	12.7	10.6	10.1	13.2	2.20	0.73
% BW	2.8	2.5	2.3	3.0	-	-
% Utilization	56	51	43	61	6.80	0.34
2017						
ADG (kg d^{-1})	0.72	0.98	0.88	0.73	0.10	0.19
AGD (AUD ha^{-1})	92bc	121a	109ab	74c	6.29	**<0.01**
TBP (kg ha^{-1})	67bc	120a	95ab	55c	11.89	**0.01**
% Utilization	61	56	52	58	6.24	0.82
Mean (2016-2017)						
ADG (kg d^{-1})	0.75	0.91	0.80	0.77	0.06	0.32
AGD (AUD ha^{-1})	112ab	131a	123ab	98b	18.38	**0.04**
TBP (kg ha^{-1})	86ab	116a	97ab	78b	13.14	**0.05**
% Utilization	58	53	49	60	5.35	0.44

[z]ALF = AC Yellowhead alfalfa; HBG = AC Success hybrid bromegrass; SF = AC Mountainview sainfoin; RWR = Tom Russian wildrye.
[y]ADG = average daily gain; AGD = animal grazing days; BW = body weight
AUD = animal unit day, based on one animal unit (or 455 kg animal).
SEM = standard error of the mean
[a-b] Means within a row with different letters differ ($P < 0.05$)

Table 5.2. Effect of Binary Mixtures on Estimated Dry Matter Intake, Forage Utilization and Grazing Heifer and Steer Performance in 2016 and 2017 at WBDC

	Treatment					
	ALF-RWR[z]	ALF-HBG	SF-HBG	SF-RWR	SEM	*P*-value
2016[x]	------------------------------------					
ADG[y] (kg d^{-1})	0.66	0.47	0.58	0.62	0.10	0.59
AGD (AUD ha^{-1})	109	115	98	116	12.97	0.73
TBP (kg ha^{-1})	73	52	54	76	15.09	0.59
DMI (kg d^{-1})	10.9	10.3	10.0	10.2	0.32	0.29
% BW	2.9	2.7	2.6	2.7	-	-
% Utilization	47	40	38	31	9.49	0.70
2017						
ADG (kg d^{-1})	0.88ab	0.64b	0.88ab	1.10a	0.10	**0.02**
AGD (AUD ha^{-1})	78	99	88	80	7.99	0.26
TBP (kg ha^{-1})	67	58	78	87	10.25	0.25
% Utilization	51	50	57	53	4.99	0.78
Mean (2016-2017)						
ADG (kg d^{-1})	0.77ab	0.56b	0.73ab	0.84a	0.16	0.04
AGD (AUD ha^{-1})	93	107	93	98	13.42	0.50
TBP (kg ha^{-1})	70	55	66	81	8.86	0.24
% Utilization	49	45	46	43	8.37	0.94

[z]ALF = AC Yellowhead alfalfa; HBG = AC Success hybrid bromegrass; SF = AC Mountainview sainfoin; RWR = Tom Russian wildrye.
[y]ADG = average daily gain; AGD = animal grazing days; BW = body weight
AUD = animal unit day, based on one animal unit (or 455 kg animal).
SEM = standard error of the mean
[x] Heifers grazed on binary mixtures
[a-b] Means within a row with different letters differ ($P < 0.05$)

5.4 Discussion

5.4.1 Estimated Dry Matter Intake and Forage Utilization

According to Vallentine (2001), it is suggested that forage dry matter intake (DMI) by grazing animals is determined by a large number of animal (physical, physiological and psychogenic), forage, weather and management factors. Dry matter intake of the current study ranged from 10.1 to 13.2 kg d^{-1} (2.3 to 3.0% BW) and 10.2 to 10.9 kg d^{-1} (2.6 to 2.9% BW) at AAFC SCRDC and WBDC, respectively. This is similar to a 3-yr study evaluating two perennial forage system (grazing stockpiled and drylot pen feeding of round bale of alfalfa (cv. Algonquin) and meadow bromegrass (cv. Paddock) at WBDC (Kulathunga et al., 2016), ranging from 9.9 to 22.6 kg d^{-1} (1.6 to 3.4 body weight). The authors explained that effective ambient temperature dropping below the lower critical temperature influenced high intake by grazing cows as extra energy is needed for body thermoregulation. However, in this current study, high intake values observed was a result of steers ingesting more to satisfy their nutrient requirements (Vallentine, 2001) on low quality forages (> 50.0% NDF) (NASEM, 2016). In addition, a 2-yr grazing study evaluating three bromegrass species (cv. AC Knowles, Paddock and Carlton) as pasture at WBDC (Lardner et al., 2015), found intake values similar to the current study at both sites. Thompson (2003), also reported DMI values of 7.6 to 11.8 kg d^{-1} when evaluating four perennial grass species (bromegrasses cv. Carlton, Paddock and AC Knowles, and crested wheatgrass) at WBDC for spring and summer grazing. The presence of ALF and SF in the current study may have caused DMI during late summer and fall months to be similar to DMI of earlier studies in spring and summer months. This agrees with studies by Popp et al. (2000) and Frame (2005), that voluntary intake of legumes are 28% greater compared to equally digestible grasses.

According to Vallentine (2001), feed intake by grazing beef cattle indicated that with more digestible roughages, DMI is increased compared to less digestible roughages as a result of reduced retention time in the reticulorumen which is regulated by the rate of digestion. In addition, Walton (1983), suggested that DMI of 2 to 2.5% body weight of grazing animals is considered palatable and high quality. This suggests that binary mixtures in the current study are palatable and more digestible thereby reducing retention time in the reticulorumen for DMI value of 2.3 to 3.0% body weight at both sites. A study by Allen (1996), evaluating physical constraints on voluntary intake of forages by ruminants found that intake varies inversely with the filling capacity of forages, which is represented by fibre mass. The author added that an animal's capacity for fill depends on the weight and volume of digesta that causes distension and flow rate of digesta from the reticulorumen. The author reported that NDF generally ferments and passes from the reticulorumen more slowly than other dietary constituents, it has a greater filling effect over time than non-fibrous feed components and has been found to be the best single chemical predictor of voluntary dry matter intake. However, the study suggested that many other factors affect reticulorumen fill, including particle size, chewing frequency and effectiveness, particle fragility, indigestible NDF fraction, rate of fermentation of the potentially digestible NDF, and characteristics of reticular contractions. Although NDF levels of binary mixtures at both sites were considered as low quality (> 50.0%) according to NASEM (2016), the other many factors suggested by Allen (1996), explains why DMI of the current study were 2.3 to 3.0% body weight of grazing animals at AAFC SCRDC and WBDC sites.

Dry matter intake data were not reported in 2017 at both sites because values were 29.0 to 36.2 kg d^{-1} (8.8 to 10.7% BW) and 23.9 to 31.6 kg d^{-1} (5.8 to 8.5% BW) at WBDC and AAFC SCRDC, respectively. A similar observation was made by De Leeuw and Bakker (1986), who concluded that calculations of forage intake made from herbage disappearance overestimated the amount of herbage consumed because of losses due to trampling are included. The authors added that as such, many DMI estimates exceeded biological capacity of the animal. In addition, Smit et al. (2005), suggested that harvesting of sward techniques are normally associated with large variation in DMI, which can be assocciated with pasture variations for both pre- and post-grazing estimation of herbage mass. In the current study, twenty, and ten 0.25 m^2 quadrats were used in each paddock to account for variability in standing forage biomass as well as forage removal at WBDC and AAFC SCRDC, respectively. However, estimated DMI ranged from 29.0 to 36.2 kg d^{-1} (8.8 to 10.7% BW) and 23.9 to 31.6 kg d^{-1} (5.8 to 8.5% BW) at WBDC and AAFC SCRDC, respectively. In addition, a 3- yr study comparing four techniques for estimating forage DMI by grazing beef cattle (Undi et al., 2008), found similar intake values compared to the current study at both sites. The authors found that the cage technique (herbage disappearance) estimated average DMI of animals in each pasture of 17.5 $\pm$ 11.61 kilogram. This was highest ($P < 0.05$) with extreme values ranging from 0.3 to 15.2% BW than estimates from the Net Energy equation, Minson equation and N-alkane marker technique. The authors also found a positive linear relationship ($r = 0.44$; $P = 0.002$) between cage DMI and standing forage biomass and suggested that high intake estimates was a result of trampling and other losses in the paddocks. This explains why estimated intake values were 10.4% greater at WBDC compared to AAFC SCRDC site. This suggests that herbage disappearance technique should be validated with other techniques for accuracy.

A 3-yr study evaluating two perennial forage system at WBDC (Kulathunga et al., 2016), found greater utilization (57.8 to 95.9%) compared to the current study. The colder weather from fall to winter months compared to late summer to fall months of the current study could have increased forage utilization. This agrees with a study by Pearson (1975), who reported that weather and trampling by grazing animals accounted for about 10% greater forage utilization in the moderately grazed unit than light or heavy grazed unit. In an extensive review of enhancing pasture productivity with alfalfa (*M. sativa* L.) (Popp et al., 2000), found similar forage utilization results compared to the current study. Thompson (2003), evaluating four perennial grass species at WBDC also found similar forage utilization results compared to the current study. A 6-yr study to evaluate effects of grazing dates on forage and beef production at AAFC SCRDC (Schellenberg et al., 1999), found that date of grazing did not affect percentage utilization of the mixed prairie rangeland. This explains why percent utilization of the current study at both sites were similar to earlier grazing studies conducted in spring and summer months. The author also found that percent utilization of forages was lower in yrs of greater forage production. This explains why percent utilization was lower (31 to 47%) in 2016 compared to 2017 at WBDC site.

According to Popp et al. (2000), it is suggested that forage intake varies inversely with forage utilization as plants mature. The author found that as plants mature, and utilization increased beyond 70%, intake is reduced which lowers animal production. However, high rates of gain could be maintained at utilization levels over 70% only in the spring months. This suggests that 50 to 60% forage utilization is optimum for high intake and animal performance after spring months.

5.4.2 Average Daily Gain

According to Hart et al. (1983), performance of grazing animals is dependent upon a number of factors, including forage quality and intake, with forage intake influenced by forage quality. However, as plants mature over the growing season, their nutritive value declines as a result of increase in NDF and ADF concentrations and decrease in IVOMD and CP concentration (Van Soest, 1994; Jefferson et al. 2004; Biligetu et al., 2014; McGeough et al., 2018). Based on previous studies, it is suggested that ADG of grazing animals would be lower in this current study compared to grazing studies in spring and summer months. However, this is different in this current study due to the presence of ALF and SF which improved CP and lowered ADF and NDF concentrations (Frame, 2005 and Cox, 2013). Average daily gain of the current study ranged from 0.71 to 0.98 kg d^{-1} and 0.47 to 1.10 kg d^{-1} at AAFC SCRDC and WBDC, respectively. This is similar to previously published animal gain data for species included in the current study in Table 5.3.

Table 5.3. Steers Performance on Spring and Summer Grazed Perennial Legume, Grass and Mixtures in Western Canada

Pasture type	ADG^z (kg d^{-1})	TBP (kg ha^{-1})	Reference
Alfalfa (*M. sativa* L.)-meadow bromegrass & Russian wildrye^x	0.7-1.5	107-462	Popp et al., 1997
Alfalfa (*M. sativa* L.)- sainfoin (cv. Nova) ^{y}	1.2	752	Berg, 1997
Sainfoin (cv. Mountainview)-alfalfa (cv. Beaver, AC Blue J)	0.7-1.2	126-593	Sottie, 2014
Alfalfa (*M. sativa* L.)-sainfoin (cv. Mountainview)	1.1	226	Acharya et al., 2013
Alfalfa (cv. Drylander.)-Russian wildrye (cv. Mayak) ^{x}	1.0-1.2	105-123	Kilcher, 1982
Alfalfa (cv. Rangelander)-Russian wildrye (cv. Swift)	0.9-1.0	107 -125	Holt and Jefferson, 1999
Russian wildrye (cv. Swift)	0.7-1.2	68-94	Holt, 1995
Hybrid bromegrass (cv. AC Knowles)	1.1	-	Lardner et al., 2015
	0.7-1.6	74-183	Thompson et al., 2003

^{z}ADG = Average daily gain; TBP = total beef production
^{y}Indicates under irrigation
^{x}Indicates fertilized

Similar AGD observed in the current study could be assumed that all binary mixtures provided similar levels of nutrition and intake, which may explain similar average daily gain. Sottie (2014), found similar ADG among alfalfa-sainfoin mixtures at AAFC SCRDC and

Lethbridge, Alberta comparable to the current study. The author explained similar ADG among treatments at both sites as similar levels of nutrition and dry matter intake. This also agrees with a 5-yr study comparing four grass (Russian wildrye cv. Mayak, meadow bromegrass etc.)–alfalfa (cv. Drylander) mixtures for productivity and persistence when grazed during spring and summer months at AAFC SCRDC (Holt and Jefferson, 1999). The authors explained similar ADG as the presence of alfalfa masking the differences among binary mixtures in average daily gains. Differences in ADG in 2017 at WBDC was because of differences in the level of nutrition among binary mixtures (Horn et al., 1979; Lardner et al., 2013). Furthermore, studies by Thompson et al. (2003), Lardner et al. (2013; 2015), evaluating steer performances on three bromegrass species at WBDC had similar ADG among treatments which was similar to the current study. This is because the earlier studies had similar nutritive value which reflected in average daily gain. This suggests that nutritive value of forages and intake are key in determining average daily gain of grazing beef cattle.

5.4.3 Animal Grazing Days

Several grazing studies in North America have shown that it is difficult to determine a stocking rate that will be similar for the entire grazing season in a put-and-take grazing system (used in this study). However, AGD will provide insight as to the carrying capacity of the pasture (Holechek et al. 1999; Vallentine, 2001; Lardner et al., 2013). The grazing capacity data of each binary mixtures were converted to animal unit equivalents (AUE) to account for differences in body weight (AUE = $BW^{0.75}/ 455^{0.75}$) and is expressed as AGD per hectare (animal unit days (AUD) ha^{-1}). For all binary mixtures over the 2-yr grazing trial, stocking rates varied from (5.7 heifers ha^{-1} in 2016; 4.3 steers ha^{-1} in 2017) at WBDC and (2.3 to 3.8 in 2016; 3.8 steers ha^{-1} in 2017) in both yrs at AAFC SCRDC site.

Animal grazing days in the current study ranged from 74 to 140 AUD ha^{-1} and 78 to 116 AUD ha^{-1} at AAFC SCRDC and WBDC, respectively. This is similar to a 6-yr grazing study of Russian wildrye at AAFC SCRDC (Holt, 1995). The author reported an average animal grazing day of (116 AUD ha^{-1}). In addition, a 2-yr grazing study at WBDC (Thompson et al., 2003), found similar animal grazing days of 99 to 102 AUD ha^{-1} on hybrid bromegrass pasture comparable to the current study. The authors suggested similar animal grazing days due to similar forage biomass yield of treatments. This agrees with studies reported by Schellenberg et al. (1999), and Holt and Jefferson (1999), that animal grazing days varies proportional to yield of individual forage species and total available yield which is also influenced by precipitation. Cohen et al. (2004), supported earlier studies that increasing forage production via N fertilization (> 100 kg N ha^{-1}) can provide greater animal grazing days. The authors conducted a 4-yr grazing study to evaluate the effects of nitrogen fertilizer on performance of pregnant yearling heifers at WBDC and obtained AGD ranging from 92 to 499 AUD ha^{-1} with greater AGD typically the results of timely precipitation and high N fertilization. In addition, Kopp et al. (2003), supported earlier studies that increasing forage production via N fertilization (110 kg N ha^{-1}) and incorporation of alfalfa (cv. Spredor II) into grass pastures can provide greater animal grazing days. The authors conducted a 4-yr study to determine the effects of forage type and fertilization on yield and quality of dryland pastures at Brandon, Manitoba and obtained AGD ranging from 128 to 209 AUD per hectare. The authors reported that incorporation of alfalfa, fertilization of meadow bromegrass and incorporating alfalfa with fertilization improved animal grazing days by 28, 64 and 57%, respectively.

Significant difference (*P* < 0.01) observed in animal grazing days in 2017 at AAFC SCRDC could be due to yield of individual forage species (Schellenberg et al., 1999 and Holt and Jefferson, 1999). This agrees with report that RWR is well adapted to the Brown soil zone and has better regrowth potential compared to hybrid bromegrass (Saskatchewan Forage Council, 2007). In addition, Holechek et al. (1999), suggested that stocking rates may affect forage production differently depending on range site and plant species. This may also explain why animals grazing days differed (*P* < 0.01) in 2017 at AAFC SCRDC site.

The fact that forage yields of binary mixtures differed (*P* = 0.01) at WBDC, but similar animal grazing days were observed suggests other factors could also influence animals grazing days. These factors may include same grazing period, similar weight of grazing animals and similar forage utilization and trampling losses. This agrees with studies by Hodgson (1990) and Bates (1993), that similar size or weight of grazing animals reduces herhage yield same via estimated intake and total utilization. In contrast, the results at WBDC disagrees with Holechek et al. (1999), who reported that carrying capacity declines similarly when stocking rate is increased. This suggests that similar carrying capacity or animal grazing days observed at WBDC on different treatments (forage production) (*P* = 0.01), may be due to under utilization of ALF-HBG and SF-HBG mixtures and efficient utilization of SF-RWR and ALF-RWR mixtures by stocker animals at same stocking rate. This would explain why animal grazing days were similar in both yrs at WBDC despite differences in mixture yield.

5.4.4 Total Beef Production

Total beef production of the current study ranged from 55 to 120 kg ha^{-1} and 52 to 87 kg ha^{-1} at AAFC SCRDC and WBDC, respectively. This is similar to a 6-yr grazing study of Russian wildrye (cv. Swift) at AAFC SCRDC (Holt, 1995). However, other studies (Berg, 1997; Popp et al., 1997; Schlegel et al., 2000; Acharya et al., 2013 and Sottie, 2014), reported greater total beef production compared to the current study.

The fact that these authors reported similar ADG (Table 5.3) compared to the current study, suggest that lower total beef production in the current study was assumed to be due to low animal grazing days. In support, Schlegel et al. (2000), reported total beef production of 159 to 689 kg ha^{-1} on pure alfalfa stand grazed by steers for 69 to 118 d while Popp et al. (1997), reported total beef production of 107 to 462 kg ha^{-1} on grass + alfalfa mixture pastures grazed by steers for 95 to 142 days. In addition, Sottie (2014), reported total beef production of 126 to 593 kg ha^{-1} on sainfoin + alfalfa mixture pasture grazed by steers for 21 to 61 days. This agrees with report by Forage and Grazing Terminology Committee (1992), that total beef production is a product of ADG and animal grazing days. The greater AGD of 121 and 109 AUD ha^{-1} for ALF-HBG and SF-HBG mixtures resulted in greater (P = 0.01) TBP compared to SF-RWR and ALF-RWR mixtures in 2017 at AAFC SCRDC (Forage and Grazing Terminology Committee, 1992).

The current study supports the model by Jones and Sandland (1974), that increased stocking rate or grazing pressure causes decline in ADG and increases total livestock production. The current study agrees to the results of 25 north American stocking rate studies by Holechek et al. (1999). The authors found that ADG of steer/calf were 1.04, 0.98, and 0.83 kg d^{-1}, respectively, under light, moderate, and heavy stocking rates; however, corresponding steer/calf unit gains were 25.1, 37.9 and 44.8 kg ha^{-1}, respectively. The current study also supports the model by Jones and Sandland (1974), that individual gain may be sacrificed at higher stocking rates but there is the potential to maximize overall animal gain on the pasture with an optimum stocking rate. However, the higher stocking rate of 2.3 to 5.7 steers ha^{-1} used in the current study did not produce better TBP (52 to 120 kg ha^{-1}) as compared to Popp et al. (1997), who reported TBP of 107 to 462 kg ha^{-1} in steers grazing alfalfa + grass mixture pastures with stocking rates of 1.1 and 2.2 steers per hectare. This may be that steers in the current study had lower grazing days (22 to 47 d) and grazed less than 60% of the available forage in each paddock as compared 69 to 118 d of grazing and 70% or more utilization (Popp et al., 1997).

Furthermore, Vallentine (2001) reported that livestock production per head/ or ha varies proportional to the quantity and/or quality of available forages and efficiency of harvest (utilization) at a constant stocking rate. The author added that increasing stocking rate increases efficiency of harvest (frequency and severity of defoliation of plants) and initially, animal production per unit area. In other words, reducing stocking rate decreases efficiency of harvest and animal production per unit area (or increasing animal gain per head). This suggests that low efficiency of herbage utilization of ALF-HBG and SF-HBG mixtures at WBDC in 2016 and 2017 resulted in similar animal gain per unit area despite greater biomass yield compared to SF-RWR and ALF-RWR mixtures. This explains why total beef production of ALF-HBG and SF-HBG mixtures were similar to RWR in mixtures with ALF or SF at WBDC site.

The result is a model that suggests that as stocking rate increases, gain per animal decreases and that there is an optimum stocking rate that will maximize total beef production per hectare. Using this model, ADG will be expected to be higher at low stocking rates than at high stocking rates. At either low or high stocking rates, TBP will be expected to be negatively impacted compared to a moderate (optimum) stocking rate.

Therefore, based on Jones and Sandland's (1974) model, it is likely that binary mixtures in the current experiments would be consistent with the linear relationship between individual animal gain and stocking rate as well as the quadratic relationship between gain per hectare and stocking rate.

5.5 Conclusion

Improving or maintaining forage production, efficient usage of forage produced, and sustaining high forage and animal production are objectives of many grazing trials. This grazing study evaluated the potential of binary pasture mixtures for use by beef production systems in summer and fall months at both AAFC SCRDC and WBDC sites. Over 2-yr, yearling beef cattle showed similar DMI at both sites as a result of similar levels treatment forage quality. High forage DMI of 10.1 to 13.2 kg ha^{-1} (2.3 to 3.0% BW) showed that binary mixtures are palatable and high quality (Walton, 1983) hence likely to reduce retention time in the reticulorumen. Large variations in DMI as a result of pasture variations for both pre- and post-grazing estimation of herbage mass and losses from trampling lower the accuracy of herbage disappearance technique (De Leeuw and Bakker, 1986; Smit et al., 2005). Other techniques such as Net Energy equation, Minson equation and N-alkane marker technique can be used to validate DMI from herbage disappearance to ensure accuracy.

Performance of grazing animals is dependent upon nutritive value of binary mixtures and estimated intake (Hart et al., 1983). Similar levels of nutrition and estimated intake produced similar average daily gain at both sites. Average daily gain was higher at low stocking rate. Increasing forage production via precipitation and fertilization increases the animal grazing days (Cohen et al. 2004). Total beef production was greater at high stocking rate and lower at low stocking rate (Jones and Sandland, 1974). High estimated intake which translated into great animal performance of binary mixtures at both sites make the treatments good candidate for late summer and fall grazing.

5.6 References

Aasen, A and Bjorge, M. 2009. Alberta forage manual. Alberta Agriculture and Rural Development. Edmonton, Alberta.

Allen, M.S. 1996. Physical Constraints on Voluntary Intake of Forages by Ruminants. J. Anim.

Campbell, J.B. 1963. Grass-alfalfa versus grass-alone pastures grazed in a repeated seasonal pattern. J. Range Manage. 14: 78–81.

Canadian Council on Animal Care. 2009. Guide to the care and use of experimental animals No. 1. Olfert, E. D., Cross, B. M. and Mc William, A. A., Canadian Council on Animal Care.Ottawa, ON, Canada.

Cohen, R.D.H., Wright, S.B.M., Thomas, L.R., McCaughey, W.P. and Howard, M.D. 2004. Current and residual effects of nitrogen fertilizer applied to grass pasture on production of beef cattle in central Saskatchewan. Can. J. Anim. Sci. 84: 91–104.

Cox, S.R. 2013. Forage yield and quality of binary grass-legume mixtures of tall fescue, orchardgrass, meadow brome, alfalfa, birdsfoot trefoil, and cicer milkvetch. MSc Thesis. Utah State University, Logan, Utah.

De Leeuw, J. and Bakker, J.P. 1986. Sheep-grazing with different foraging efficiencies in a Dutch mixed grassland. J. Appl. Ecol. 23:781–793.

Forage and Grazing Terminology Committee. 1992. Terminology for grazing lands and grazing animals. J. Prod. Agric., 5: 191–201.

Frame, J. 2005. Forage Legumes for Temperate Grasslands. Enfield, NH, USA.: FAO. Science Publishers, Inc.

Hanna, M.R., Kozub, G.C. and Smoliak, S. 1977. Forage production of sainfoin and alfalfa on dryland in mixed and alternate row seedings with three grasses. Can J. Plant Sci. 57: 61–70.

Hart, R.H., Balla, E.F., Waggoner Jr., J.W. 1983. Gains of steers and calves grazing crested wheatgrass. J. Range Manag. 36:483–485.

Hodgson, J. 1990. "Grazing Management: Science into Practice." John Wiley & Sons, New York.

Holechek, J.J., Gomez, H., Molinar, F. and Galt, D. 1999. Grazing studies: what we've learned. Rangelands 21(2): 12–16.

Holechek, J.L., Vavra, Me and Pieper, R.D. 1981. Diet quality and performance of cattle on forest and grassland range. J. Anim. Sci. 52: 291–299.

Holt, N. and Jefferson, P.G. 1999. Productivity and sustainability of four grazed grass - alfalfa mixtures. Can. J. Anim. Sci. 79(1): 83–89. http://doi.org/10.4141/A98-064

Holt, N. W. 1995. Effect of snow fence or trimming seed heads or stems of Russian wildrye on April soil water content, forage and beef production. Can. J. Animal. Sci. 75: 309-314.

Horn, F.P., Telford, J.P., McCroskey, J.E., Stephens, D.F., Whiteman, J.V. and Totusek, R. 1979. Relationship of animal performance and dry matter intake to chemical constituents of grazed forage. J. Anim. Sci. 49: 1051–1058

Jasmer, G.E. and Holechek, J.L. 1984. Determining grazing intensity on rangeland. J. Soil Water Conserv. 39: 32–35.

Jefferson, P.G., McCaughey, W.P., May, K., Woosaree, J. and McFarlane, L. 2004. Forage quality of seeded native grasses in the fall season on the Canadian Prairie Provinces. Can J. Plant Sci., 84:503–509.

Jones, R. J. and Sandland, R. L. 1974. The relation between animal gain and stocking rate: derivation of the relation from the results of grazing trials. J. Agric. Sci. (Camb.).83: 335-342

Judy, J.V. 2014. Effects of stocking rate on forage nutrient composition of Nebraska sandhills upland range when grazed in early summer and the effects of grazing on Nebraska sandhills meadow forage nutrient composition. Msc. Thesis. Department of Animal Science. University of Nebraska, Lincoln, Nebraska

Kopp, J.C., McCaughey, W.P. and Wittenberg, K.M. 2003. Yield, quality and cost effectiveness of using fertilizer and/or alfalfa to improve meadow bromegrass pastures. Can. J. Anim. Sci. 83: 291–298.

Kulathunga, D.G.R.S., Penner, G.B., Schoenau, J.J., Damiran, D., Larson, K., & and Lardner, H. 2016. Effect of perennial forage system on forage characteristics, soil nutrients, cow performance, and system economics. The Prof. Animal Sci. 32: 784–797.

Lardner, H.A , Wright, S.B.M., Cohen, R.D.H., Curry, P and MacFarlane, L. 2000. The effect of rejuvenation of Aspen Parkland Ecoregion grass-legume pastures on dry matter yield and forage quality. Can. J. Plant Sci. 80: 781–791.

McGraw, R.L., Shockley, F.W. Thompson, J.F. and Roberts, C.A. 2004. Evaluation of native legume species for forage yield, quality, and seed production. Native Plants. Fall 2004.

Ogle, D., St. John, L., Cornwell, J., Holzworth, L., Majerus, M., Tober D., Jensen, K., Sanders, K.E. (rev) St. John. 2012a. Plant Guide for Russian Wildrye *(Psathyrostachys junceus).* USDA-Natural Resources Conservation Service, Aberdeen Plant Materials.

Pearson, H.A. 1975. Herbage Disappearance and Grazing Capacity Determinations of southern Pine Bluestem Range. J. Range Mgt. 28(1): 71–73.

Popp, J.D., McCaughey, W.P. Cohen, R.D.H. McAllister, T.A. and Majak, W. 2000. Enhancing pasture productivity with alfalfa: A review. Can. J. Plant Sci. 80: 513–519.

Popp, J.D., McCaughey, W.P. and Cohen, R.D.H. 1997. Grazing system and stocking rate effects on the productivity, botanical composition and soil surface characteristics of alfalfa-grass pastures. Can. J. Anim. Sci. 77: 669–676

Schellenberg, M.P., Holt, N.W. and Waddington, J. 1999. Effects of grazing dates on forage and beef production of mixed prairie rangeland. Can. J. Anim. Sci., 79: 335–341.

Schlegel, M.L., Wachenheim, C.J., Benson, M.E., Black, J.R., Moline, W.J., Ritchie, H.D., Schwab, G.D. and Rust, S.R. 2000. Grazing methods and stocking rates for direct-seeded alfalfa pastures: I. Plant productivity and animal performance. J. Anim. Sci. 78: 2192–2201.

Smit, H. J., Taweel, H. Z., Tas, B. M., Tamminga, S. and Elgersma, A. 2005. Comparison of techniques for estimating herbage intake of grazing dairy cows. J. Dairy Sci. 88: 1827-1836

Sottie, E.T. 2014. Characterization of new sainfoin populations for mixed alfalfa pastures in western Canada. PhD Thesis. University of Lethbridge, Lethbridge, AB

Thompson, L.C., Lardner, H.A., Cohen, R.D.H. and Coulman, B.E. 2003. Steer performance grazing hybrid bromegrass pastures. Can. J. Anim. Sci. 83: 165–169.

Thompson, L. 2003. Forage production and performance of beef yearling graziing hybrid bromegrass. MSc. Thesis. Dept. of Animal and Poultry Science. University of Saskatchewan, Saskatoon, SK.

Thonney, M.L., Duhaime, D.J., Moe, P.W. and Reid, J.T. 1979. Acid insoluble ash and permanganate lignin as indicators to determine digestibility of cattle rations. J. Anim. Sci. 49: 1112–1116.

Thornton, R.F. and Minson, D.J. 1973. The relationship between apparent retention time in the rumen, voluntary intake, and apparent digestibility of legume and grass diets in sheep. Aust. J. Agric. Res., 24: 889–898.

Undi, M., Wilson, C., Ominski, K.H. and Wittenberg, K.M. 2008. Comparison of techniques for estimation of forage dry matter intake by grazing beef cattle. Can. J. Anim. Sci. 88: 693–701.

Vallentine, J.F. 2001. Grazing Management. 2nd edition. Academic Press.San Diego, CA. Retrieved from http://www.sciencedirect.com/science/article/B83X7-4MSSPMB-S/2/05b99c4e7ed635ec474f319de08a4480

Van Soest, P.J. 1994. Nutritional Ecology of the Ruminant. 2nd edn., Cornell University Press, Ithaca, New York.

Walton, P.D. 1983. The production and management of cultivated forages.Reston Publishing Company, Inc. Reston, Virginia.

Ward, C.I. 2009. The effect of perennial grass species on forage growth and quality, etiolated growth, animal performance and economics. MSc Thesis. University of Saskatchewan, Saskatoon, SK.

Western Beef Development Centre. 2015. Western Canadian cow-calf survey. http://westernbeef.org/pdfs/economics/WCCCS_Summary_Overall_Jun2015.pdf.

6 Economic Analysis of Binary Legume-Grass Mixtures for Beef Production

6.1 Introduction

The productivity of pastures in the temperate regions of the world is limited largely by the availability of nitrogen**.** Symbiotic N fixation via legumes and N fertilizers are two sources available to the forage manager to meet the N requirements of the crop. The cost of N fertilizers during 2000 to 2007 rose by 120% and weighed heavily on the profitability of beef producers (USDA, 2009). However, in Alberta, Canada cost of N fertilizers had declined since 2015 by 19 percent (Alberta Agriculture and Forestry, 2018). Economic alternatives to commercial fertilizers do exist. Grass-legume mixed production systems may be a better option not only for reducing production costs, but also for environmental and health reasons associated with N fertilized grass production systems (Lauriault et al., 2003). While the quantity and quality of forages are important for evaluating pasture carrying capacity and grazing livestock performance, it is also beneficial to assess the economic viability of these systems.

Perennial pasture serves as a feed source to maintain pregnant beef cows as well as grow yearling stockers and weaned calves. A study by the Saskatchewan Forage Council (SFC) (2011), has shown that effective utilization of pasture hectares within grazing management systems is essential to maintaining the economical viability of cow/calf enterprises. Cost of production results show that winter feed is the largest cost for the cow/calf enterprise (Alberta Agriculture and Forestry (AA&F), 2017), accounting for 40% of annual costs in 2017. As such, efforts that extend the number of days grazing forage systems are used enables beef producers to save on overall production costs. As part of the SFC study, rates for grazing communal land or land managed by government agencies were reported to range from \$ 0.40 to \$ 0.55 per cow per day.

Between 2012 to 2016, winter feed and bedding costs averaged \$ 1.82 cow^{-1} feeding day^{-1} in Alberta (current results do not exist for Saskatchewan) (AA&F, 2017). The average winter-feeding period was 179 days (December to May). The average cost per grazing day was \$ 1.24 $pair^{-1}$ day^{-1}, a 32% cost difference. Total production costs were \$ 782.05 cow^{-1}, or \$ 3.26 kg^{-1} of weaned calf.

With the abolishment of the Crow rate in 1995, there has been a shift for many producers to increase their perennial forage acreage and/or the number of livestock they own. When the Crow rate was abolished, freight rates increased and many grain farmers looked for ways to use their grain on-farm (ie. feed for livestock). However, for many producers this change has been limited by cash flow restrictions, lack of infrastructure or a lack of desire to raise livestock. Furthermore, if producers do not have significant land base to sustain a livestock operation or readily accessible water sources suitable for livestock, grazing may be not be a feasible option for them.

Before a producer decides what is the best option for their farming operation it is important to consider alternative land uses and weigh the advantages, disadvantages and economics of all options.

The objective for this chapter is to economically evaluate binary mixtures grazed by stocker animals. The study site had a goal of 60 d grazing with 3 to 4 animals per paddock and gains in the range of 0.9 kg hd^{-1} d^{-1}. Costs for stand establishment included: (i) seed, (ii) fertilizer, (iii) herbicide, (iv) equipment, labour, (v) fencing and water infrastructure. Benefits for each binary mixture were derived from actual animal weight gains valued at current market prices and going rates for custom grazing.

6.2 Materials and Methods

6.2.1 Costs of Establishing Binary Mixtures

Binary mixtures establishment expenses included all costs associated with production of the forages at AAFC SCRDC and WBDC (2016 and 2017) are presented in Tables 6.1, 6.2, and 6.3, respectively. This included land preparation pre-seeding, pre and post seed herbicide application, seed, seeding, inoculating (sainfoin), fertilizer application (AAFC SCRDC) and land rent were based on custom rates from the Farm Machinery Custom and Rental Rate Guide (SMA, 2016). Cost of seeds were \$ 13.68, \$ 18.50, \$ 9.90 and \$ 12.21 kg^{-1} for SF, ALF, RWR and HBG, respectively.

Table 6.1. Cost of Establishing Binary Legume-Grass Mixtures at AAFC SCRDC (\$ ha^{-1}) (2015-2016)

	Treatment			
2015-2016	ALF-RWR[z]	ALF-HBG	SF-RWR	SF-HBG
	----------------------------\$ ha^{-1}----------------------------------			
Pre-seeding Glyphosate	39.68	39.68	39.68	39.68
Spraying	12.35	12.35	12.35	12.35
John Deere 1590 Double Disc Press	44.46	44.46	44.46	44.46
Seeds	111.77	153.98	202.43	244.64
Inoculant	-	-	2.38	2.38
Fertilizer	52.02	52.02	52.02	52.02
Spraying	12.35	12.35	12.35	12.35
In-field herbicide application	62.31	62.31	62.31	62.31
Over-seeding paddock	82.34	95.83	166.47	179.95
Perimeter electric fencing	160.84	160.84	160.84	160.84
Dugout	9.65	9.65	9.65	9.65
Total pasture establishment cost	587.77	643.47	764.94	820.59
Expected years of use	10.00	10.00	10.00	10.00
Cost per year of expected use	58.78	64.35	76.49	82.06

[z]ALF = AC Yellowhead alfalfa; SF = AC Mountainview sainfoin; RWR = Tom Russian wildrye; HBG = AC Success hybrid bromegrass

Table 6.2. Cost of Establishing Binary Legume Grass Mixtures at WBDC ($ ha^{-1}) (2015-2016)

	Treatments			
2015-2016	ALF-RWR[z]	ALF-HBG	SF-RWR	SF-HBG
	---------------------------$ ha^{-1}---------------------------			
Pre-seeding Glyphosate	23.71	23.71	23.71	23.71
Spraying	12.35	12.35	12.35	12.35
Seed cover crop	49.40	49.40	49.40	49.40
Barley Seed-Cover crop	21.00	21.00	21.00	21.00
Agro-Plow Drill and Tractor	90.16	90.16	90.16	90.16
Seeds	111.77	153.98	202.43	244.64
Inoculant	-	-	4.48	4.48
Fertilizer	0.00	0.00	0.00	0.00
Spraying	12.35	12.35	12.35	12.35
In-field herbicide application	39.89	39.89	39.89	39.89
Over-seeding legume	159.86	159.86	119.56	119.56
Perimeter electric fencing	160.84	160.84	160.84	160.84
Dugout	9.65	9.65	9.65	9.65
Total pasture establishment cost	759.45	813.54	906.22	960.32
Less cover crop returns	469.45	469.45	469.45	469.45
Net pasture establishment cost	290.00	336.36	436.77	490.86
Expected years of use	10.00	10.00	10.00	10.00
Cost per year of expected use	28.23	33.64	43.68	49.09

[z]ALF = AC Yellowhead alfalfa; SF = AC Mountainview sainfoin; RWR = Tom Russian wildrye; HBG = AC Success hybrid bromegrass

Table 6.3. Cost of Establishing Binary Legume Grass Mixtures at WBDC ($ ha^{-1}) (2016-2017)

	Treatment			
2016-2017	ALF-RWR[z]	ALF-HBG	SF-RWR	SF-HBG
	----------------------------$ ha^{-1}	--------------------------------		
Pre-seeding Glyphosate	23.71	23.71	23.71	23.71
Spraying	12.35	12.35	12.35	12.35
Seed cover crop	49.40	49.40	49.40	49.40
Barley Seed-Cover crop	21.00	21.00	21.00	21.00
Agro-Plow Drill and Tractor	90.16	90.16	90.16	90.16
Seeds	111.77	153.98	202.43	244.64
Inoculant	-	-	4.48	4.48
Fertilizer	0.00	0.00	0.00	0.00
Spraying	12.35	12.35	12.35	12.35
In-field herbicide application	39.89	39.89	39.89	39.89
Over-seeding legume	159.86	159.86	119.56	119.56
Perimeter electric fencing	160.84	160.84	160.84	160.84
Dugout	9.65	9.65	9.65	9.65
Total pasture establishment cost	759.45	813.54	906.22	960.32
Expected years of use	10.00	10.00	10.00	10.00
Cost per year of expected use	75.95	81.35	90.62	96.03

[z]ALF = AC Yellowhead alfalfa; SF = AC Mountainview sainfoin; RWR = Tom Russian wildrye; HBG = AC Success hybrid bromegrass

At the WBDC site (Thin Black Soil zone), Maverick barley was seeded at 60 kg ha^{-1} bu prior to the forage and harvested as greenfeed hay in Fall 2015. A total of 87 bales (averaging 660 kg) were harvested from the site (10.7 ha). The market value used for the greenfeed was $ 0.09 kg^{-1} or $ 88.00 per tonne, which is a conservative valuation given greenfeed averaged over $ 0.13 kg in Fall 2015 (Saskatchewan Forage Council, 2015). The returns generated from the greenfeed totaled $ 469.44 per hectare. The value of the cover crop covered between 49 and 62% of the pasture establishment costs as shown in Table 6.2. The value of the cover crop is deducted from the pasture establishment costs and the net costs amortized over expected years of use (ten) (Western Beef Development Centre, 2015). At AAFC SCRDC, per yr costs for the pasture ranged from \$ 58.78 per hectare (ALF-RWR) to \$ 82.06 per hectare (SF-HBG) (Table 6.1). However, at WBDC, the per yr costs for the pasture ranged from \$ 28.23 vs. 75.95 per hectare (ALF-RWR) to \$ 49.09 vs. 96.03 per hectare (SF-HBG), in 2016 and 2017, respectively, (Table 6.2 and 6.3).

Prior to seeding, the site at AAFC SCRDC was sprayed with 4.9 L ha^{-1} of glyphosate (product used: RoundUp Weathermax) at a cost of \$ 39.36 ha^{-1} (\$ 8.03 per L for glyphosate plus \$ 12.35 per ha for sprayer application). At WBDC, the field was sprayed with 5.6 L ha^{-1} of glyphosate (Product used: RoundUp Transorb) at a cost of \$ 36.06 ha^{-1} (\$ 6.40 L^{-1} for glyphosate plus \$ 12.35 ha^{-1} for sprayer application) as presented in Table 6.2. Seeding was done with John Deere 1590 double disc press at a cost of \$ 44.46 ha^{-1} at AAFC SCRDC and a 2.4 m zero till seed opener Agro Plow drill and suitable horsepower tractor were rented at a cost of \$ 90.16 per hectare (\$ 38.29 ha^{-1} for Agro Plow) (Difley, personal communication, 2017), plus \$ 51.87 ha^{-1} for tractor (Saskatchewan Ministry of Agriculture, 2016). Prior to seeding at WBDC, a Maverick barley cover crop was seeded June 2, 2015 at a rate of 2.5-bushel ha^{-1} and cost of \$70.40 ha^{-1} (includes \$8.50 per bushel for seed plus \$49.40 ha^{-1} for seeding). Forage seed costs differed between treatments with ALF costing the most at \$ 18.50 kg^{-1}, SF \$ 13.68 kg^{-1}, HBG \$ 12.21 kg^{-1} and RWR the least at \$ 9.90 kg^{-1}. The plots were sown as mixtures – legume-grass – so the costs for seed ranged from \$ 111.77 ha^{-1} (ALF-RWR) to \$ 244.65 ha^{-1} (SF-HBG) at AAFC SCRDC and \$ 180.24 ha^{-1} (ALF-RWR) to \$ 416.94 ha^{-1} (SF-HBG) mixtures at WBDC site. Inoculant was applied to the sainfoin seed at 10 grams per kilogram of seed and a cost of \$ 0.02 per gram for additional cost of \$ 2.38 ha^{-1} at AAFC SCRDC and \$ 4.48 ha^{-1} at WBDC on the SF-RWR and SF-HBG mixtures plots.

An in-field application of broadleaf herbicide (Basagran Forte) at a rate of 2.2 L ha^{-1} cost $ 74.67 ha^{-1} ($ 12.35 per hectare for sprayer application plus $ 62.99 ha^{-1} for herbicide) at AAFC SCRDC and Prestige XC on June 25, 2015 cost $ 52.24 per hectare ($ 12.35 per hectare for sprayer application plus $ 40.76 ha^{-1} for herbicide at WBDC).

In Spring 2016, establishment concerns forced the re-seeding of SF and ALF in each paddock at WBDC using the Agro Plow at a cost of $ 90.16 ha^{-1} and binary mixtures on paddocks 5 to 12 (two replicates in each treatment did not require overseeding) at AAFC SCRDC using the John Deere 1590 double disc press at a cost of $ 44.46 per hectare. AC Yellowhead alfalfa was overseeded at 3.3 kg ha^{-1} and SF at 2.1 kg ha^{-1} for total over-seeding costs of $ 159.86 and $ 119.57 ha^{-1} for ALF and SF mixtures with grass species at WBDC, respectively. However, at AAFC SCRDC the binary mixtures were overseeded at 1.9, 10.8, 3.9 and 3.0 kg ha^{-1} for ALF, SF, HBG and RWR, respectively. Total over-seeding costs differed by treatment- at $ 82.34, $ 95.83, $ 166.47, $ 179.95 ha^{-1} for ALF-RWR, ALF-HBG, SF-RWR and SF-HBG mixtures, respectively.

6.2.2 Fencing and Watering Costs

Fencing costs at both study sites were calculated on a per quarter (64.8 ha) basis, assuming an entire quarter received a perimeter fence (3-wire electric) followed by two cross fences to result in four – 16.2 ha parcels. Estimated costs for fencing were sourced from the Saskatchewan Ministry of Agriculture; one mile of three-wire electric fence is estimated to cost $ 3,473.33. A total of three miles of fence would be required to erect perimeter and cross-fencing on a quarter section for a cost of $ 160.84 per hectare. The cost to dig a dugout for watering is estimated at $ 2,500 per section (259.2 ha), for a cost of $ 9.65 per hectare.

6.2.3 Amortization Over Useful Life (10 years)

Perennial forages have a large cash outlay in the establishment year, but minimal to no expenses for several years after. For the purposes of this research, the pastures are assumed to be grazed for 10 yrs before they need to be rejuvenated or re-established (Western Beef Development Centre, 2015). Amortizing the costs ($ ha^{-1}) over 10 yrs, the per yr costs for pasture establishment were ALF-RWR $ 58.78, ALF-HBG $ 64.35, SF-RWR $ 76.49 and SF-HBG mixtures $ 82.06 at AAFC SCRDC for both yrs and ALF-RWR ($ 28.23 vs. 75.95), ALF-HBG ($ 33.64 vs. 81.35), SF-RWR ($ 43.67 vs. 90.62), and SF-HBG mixtures ($ 49.09 vs. 96.03) at WBDC in 2016 and 2017, respectively.

6.2.4 Opportunity Cost Considerations

The land rent or opportunity cost of land (valued $ 96.80 ha^{-1}) is often factored into represent value (revenue) the land could have generated if it had been used in its next best alternative use (e.g. cash rented out). Including the foregone revenue from choosing to not rent out the land as an expense (albeit a non-cash expense), forces the current land use to be at least as profitable as its next best alternative use. If the pasture cannot generate \$ 96.80 ha^{-1} in revenue, a producer may be better off renting out the land. Land rent is not included in the pasture establishment costs, however, it is important to compare returns with the rent that could have been generated had the land been rented out.

6.2.5 Statistical Analysis

Cost to seed binary mixtures, value of gain and net returns data were subjected to analysis of variance (ANOVA) as a randomized complete block design (RCBD) using the SAS Mixed Model procedure (Version 9.3; SAS Inst., Inc., Cary, NC). The statistical model was:

$$Yij = \mu + \rho i + \alpha j + eij$$

where Yij is the dependent variable, μ is the overall mean, ρi is the block of the ith treatment, αj is the fixed effect of the ith treatment, and eij is the error term specific to the experimental unit (paddock) assigned to the ith treatment

The binary mixtures (treatments) were considered as a fixed effect in this initial analysis because of the differences in edaphic and climatic conditions between the study sites. Year considered as random blocking effect. The effect of treatments on cost to seed mixtures, value of gain and net returns were analyzed. The Kenwardroger option was used to estimate denominator degrees of freedom. Least square means were separated using Tukey’s multiple range test procedure and difference considered significant when $P < 0.05$.

6.3 Results and Discussion

The cost-benefits analysis of binary legume-grass mixtures at AAFC SCRDC and WBDC are presented in Tables 6.4 and 6.5, respectively. Cost to establish pasture mixtures for SF-HBG mixtures was higher ($P = 0.01$) than ALF-RWR mixture but similar to other treatments in 2016 and 2017 and over the 2 yrs at AAFC SCRDC site. Value of gain in 2017 for ALF-HBG mixture was higher (P = 0.01) than SF-RWR mixture but similar to other treatments and this was also observed over the 2 yrs. Net returns in 2017 for ALF-HBG mixture was higher (P = 0.02) than SF-RWR mixture but similar to other treatments. However, over the 2 yrs in 2016 and 2017, net returns were higher (P < 0.01) than the other treatments at AAFC SCRDC site.

However, at WBDC cost to establish pasture mixtures in 2016, 2017 and over the 2 yrs for SF-HBG was highest (P < 0.01) than SF-RWR, ALF-HBG and ALF-RWR mixtures in that order.

Table 6.4. Costs-Benefit Analysis of Binary Legume-Grass Mixtures at AAFC SCRDC ($ ha^{-1}) in 2016 and 2017

	Treatments					
	ALF-RWR[z]	ALF-HBG	SF-RWR	SF-HBG	SEM	*P*-value
2016	---------------------------------$ ha^{-1}------------------					
Cost to seed mixture	58.78b	64.35ab	76.49ab	82.06a	4.60	**0.01**
Value of gain	112.20	122.10	111.37	111.38	11.17	0.88
Net returns	53.43	57.76	34.88	29.31	12.27	0.33
2017						
Cost to seed mixture	58.78b	64.35ab	76.49ab	82.06a	4.60	**0.01**
Value of gain	62.58b	109.02a	52.07b	87.51ab	10.98	**0.01**
Net returns	3.80ab	44.68a	-24.77b	-5.10ab	13.21	**0.02**
Mean (2016-2017)						
Cost to seed mixture	55.84c	61.41bc	68.53ab	74.10a	5.96	**<0.01**
Value of gain	62.58bc	109.02a	52.07c	87.51ab	7.19	**<0.01**
Net returns	6.74b	47.61a	-16.64b	13.24b	9.28	**<0.01**

[z]ALF = AC Yellowhead alfalfa; SF = AC Mountainview sainfoin; RWR = Tom Russian wildrye; HBG = AC Success hybrid bromegrass
SEM = standard error of the mean
[a-b] Means within a row with different letters differ (P < 0.05)

Table 6.5. Costs-Benefit Analysis of Binary Legume-Grass Mixtures at WBDC (\$ ha^{-1}) in 2016 and 2017

	Treatments					
	ALF-RWR[z]	ALF-HBG	SF-RWR	SF-HBG	SEM	*P*-value
2016	------------------------------------\$ ha^{-1}----------------					
Cost to seed mixture	29.00d	34.41c	43.68b	49.09a	0.55	<**0.01**
Value of gain	76.35	55.58	80.16	60.39	16.07	0.66
Net returns	47.34	21.17	36.48	11.30	15.89	0.42
2017						
Cost to seed mixture	75.95d	81.36c	90.62b	96.03a	0.55	<**0.01**
Value of gain	82.45	67.32	98.95	91.15	11.20	0.27
Net returns	6.51	-14.03	8.33	-4.88	11.37	0.47
Mean (2016-2017)						
Cost to seed mixture	52.47d	57.88c	67.15b	72.56a	23.47	<**0.01**
Value of gain	79.40	61.45	89.55	75.77	11.72	0.23
Net returns	26.92	3.57	22.40	3.21	17.10	0.18

[z]ALF = AC Yellowhead alfalfa; SF = AC Mountainview sainfoin; RWR = Tom Russian wildrye; HBG = AC Success hybrid bromegrass
SEM = standard error of the mean
[a-b] Means within a row with different letters differ (P < 0.05)

Costs to seed mixtures ranged from \$ 58.78 (ALF-RWR) to \$ 82.06 (SF-HBG) mixtures at AAFC SCRDC as presented in Table 6.4. However, at WBDC, costs to seed mixtures ranged from \$ 29.00 (ALF-RWR) to \$ 49.09 (SF-HBG) mixtures in yr 1 and 75.95 (ALF-RWR) to \$ 96.03 (SF-HBG) mixtures in 2017 at WBDC as presented in Table 6.5. Seeds costs and inoculant use were the only costs that differed between treatments. AC Yellowhead alfalfa seed was the most expensive (\$ 18.50 kg^{-1}), however, its seeding rate was lower compared to SF (6.7 kg vs. 22.4 kg ha^{-1}) at WBDC and (3.9 kg vs. 11.9 kg ha^{-1}) at AAFC SCRDC, resulting in the treatments containing SF having the highest costs to establish.

Cost to seed mixtures at WBDC in 2017 increased 100% compared to 2016. This was because no returns from greenfeed were generated in 2017 thereby increasing the cost to seed mixtures by 100 per cent. High (26 to 47%) seeding rate of binary mixtures at WBDC compared to AAFC SCRDC was because of variations of edaphic and climatic conditions. This explains why costs to seed mixtures were an averaged \$ 16.20 greater at WBDC compared to AAFC SCRDC site. A 2-yr study to evaluate economic returns of five perennial pasture species (bromegrasses (cv. AC Knowles, Paddocks, Carlton), Goliath crested wheatgrass and Courteney tall fescue) for grazing compared to the economic returns for annual cropping at WBDC (Ward, 2009), found that cost per yr of expected use ranged from \$ 206.19 to \$ 228.53 ha^{-1}. The current study had over 100% lower cost to seed mixtures compared to an earlier work by Ward (2009), who explained higher cost to seed pasture as increase in the price of commercial fertilizers (minimally \$ 0.66 ha). The author suggested in her work that grass-legume mixtures would reduce the total reliance on commercial fertilizer which is obvious in the current study.

Yearling heifers (2016 at WBDC) and steers were used to graze the paddocks. While this study assumed that the pasture forage was harvested by custom grazing steers, it is also a possibility that producers would be grazing their own cattle (as in the case at AAFC SCRDC) on the land. If producers were to buy feeder cattle for grassing or retain their own calves to grass, it is important that they determine their cost of gain. In custom grazing situations, compensation is often based on animal weight gain rather than a cost per head per day. Compensation of gain (\$ 0.88 kg^{-1}) was the agreed upon rate between Western Beef Development Centre and the cattle owner for yearlings grazing at the WBDC site and was used for the AAFC SCRDC analysis as well for the 2-yr study. For each of the treatments, grazing animals had two-day start and end of test weights. Total grazing days ranged from 36 to 47 d in 2016 and 19 to 34 d in 2017 at AAFC SCRDC and 22 d in 2016 and 22 to 28 d in 2017 at WBDC site. Weight gains varied by treatment averaging 0.79 kg hd^{-1} d^{-1} in 2016 and 0.83 kg hd^{-1} d^{-1} in 2017 at AAFC SCRDC (Table 5.1), and 0.58 kg hd^{-1} d^{-1} in 2016 and 0.88 kg hd^{-1} d^{-1} in 2017 at WBDC across all treatments (Table 5.2).

Revenues per hectare basis (value of gain) was calculated by multiplying total kilograms gained by the animals in each replicate by the $ 0.88 per kilogram compensation rate and then divided by paddock size. Weight gain compensation ranged from $ 111.38 ha^{-1} (SF-HBG and SF-RWR) to $ 122.10 ha^{-1} (ALF-HBG) mixtures in 2016 and $ 52.07 ha^{-1} (SF-RWR) to $ 87.51 ha^{-1} (SF-HBG) in 2017 at AAFC SCRDC site. However, at WBDC, weight gain compensation ranged $ 60.39 ha^{-1} (SF-HBG) to $ 80.16 ha^{-1} (SF-RWR) in 2016 and $ 61.45 ha^{-1} (ALF-HBG) to $ 89.55 ha^{-1} (SF-RWR) in 2017.

On average, all treatments had positive net returns in 2016 at both sites ranging from $ 29.31 (SF-HBG) to $ 57.76 ha^{-1} (ALF-HBG) at AAFC SCRDC and $ 11.30 ha^{-1} to $ 47.34 ha^{-1} at WBDC site. In 2017 however, net returns ranged from $-24.77 ha^{-1} (SF-RWR) to $ 44.68 ha^{-1} (ALF-HBG) at AAFC SCRDC and $-14.03 ha^{-1} (ALF-HBG) to $ 8.33 ha^{-1} (SF-RWR) at WBDC site. It is positive to see, that despite having no cover crop revenues, all treatments at AAFC SCRDC (Brown Soil Zone) were able to generate animal weight gains to generate a positive net return in 2016. The negative net returns observed in 2017 for SF-RWR and SF-HBG mixtures at AAFC SCRDC were as a result low steer weight gains (0.73 kg d^{-1} vs. 0.88 kg d^{-1}), respectively in relation to costs of seeding SF-RWR and SF-HBG mixtures. Despite similar ADG of steers in both yrs at AAFC SCRDC, negative net returns observed in SF-HBG and SF-RWR mixtures was because of high cost to pasture establishment.

Ward (2009), examining economics of five perennial pasture at WBDC had net returns ranging from $-54.32 to 49.33 ha^{-1} in 2016 and $-99.03 to 82.95 ha^{-1} in 2017 which was lower compared to the current study. High cost of production and relatively low animal weight gain explains why the earlier study had high negative net returns compared to the current study. A study by the Western Beef Development Centre (2000-2005) evaluating the economics of Lorne Christopherson's (a mixed farmer near Weldon, Saskatchewan) conversion from 'grain to grass', rotational grazing of perennial pasture (meadow bromegrass-alfalfa) by cow-calf pairs provided greater net return ($ 57.94 ha^{-1}) compared to annual cropping systems ($ 28.80 ha^{-1}) (Lang, 2006). Thus, net returns of ALF-HBG mixtures in the current study at AAFC SCRDC is in agreement with the results of the Western Beef Development Centre's producer evaluation for perennial mixtures (Lang, 2006).

Valuing the forage at $ 0.044 per kilogram ($ 40/ton) corresponds with $0.70 per head per day grazing valuation based on the following: a cow weighing 636 kg will consume 2.5% of her body weight in dry matter (DM) each day (636 x 0.025 = 16 kg DM), the daily value of grazing is $0.70 per day (16 kg x $ 0.044). To apply this valuation, only 70% of the yield is assumed to be consumed to allow for suitable carryover. At WBDC, net returns on forage valuation were ALF-RWR ($ 76.82 vs. 46.20 ha^{-1}), ALF-HBG (174.43 vs. $ 74.03 ha^{-1}), SF-RWR (62.00 vs. $ 27.78 ha^{-1}) and SF-HBG (100.48 vs. $ 69.21 ha^{-1}), in 2016 and 2017, respectively. However, at AAFC SCRDC, net returns on forage valuation were ALF-RWR ($ 71.23 vs. 66.24 ha^{-1}), ALF-HBG (57.90 vs. $ 55.55 ha^{-1}), SF-RWR (35.79 vs. $ 34.85 ha^{-1}) and SF-HBG (36.48 vs. $ 18.61 ha^{-1}), in 2016 and 2017, respectively.

There are custom grazing situations where compensation is based on number of days grazing and not on the animal weight gain. Based on Saskatchewan Forage Council (2016), report the average grazing fee for yearling cattle was $ 0.72 $hd^{-1}d^{-1}$ and $ 1.09 $hd^{-1}d^{-1}$ for cow-calf pairs. At WBDC, net returns based on number of days grazing for custom grazing were ALF-RWR ($ 65.73

vs. \$ -1.37 ha^{-1}), ALF-HBG (65.59 vs. \$ 13.56 ha^{-1}), SF-RWR (55.80 vs. \$ -16.05 ha^{-1}) and SF-HBG (33.81 vs. \$ -11.66 ha^{-1}), in 2016 and 2017, respectively. However, at AAFC SCRDC, net returns based on number of days for custom grazing were ALF-RWR (\$ 36.80 vs. \$ 11.89 ha^{-1}), ALF-HBG (40.14 vs. \$ 26.32 ha^{-1}), SF-RWR (14.42 vs. \$ -19.51 ha^{-1}) and SF-HBG (19.76 vs. \$ 0.25 ha^{-1}), in yr 1 and yr 2, respectively.

Comparing the net returns from all three valuations – compensation for weight gain, compensation for days grazing, forage valuation. Valuation approach yielded consistent treatment rankings on net returns. Valuing forage at \$0.044 per kilogram (irrespective of days grazing or animal weights gains achieved) resulted in the highest net returns for all treatments, while valuing the forages on the basis of animal weight gain (\$0.88 kg^{-1} of gain) yielded the lowest net returns. These results illustrate that producers must carefully consider their options and expectations when negotiating compensation rates for custom grazing.

6.4 Conclusion

The differences in soil and climatic condition influenced costs to establish pasture mixtures. Higher seeding rates at WBDC resulted in higher establishment costs compared to AAFC SCRDC site. Revenue from greenfeed in 2016 at WBDC reduced cost to seed pasture mixture by 100 percent. This suggests that producers should seed an annual crop cover for revenue in 2016 to reduce costs of seeding perennial binary mixtures in 2016 since perennial pastures are not grazed in seeding (establishment) year. Negative net returns observed in ALF-HBG and SF-HBG mixtures in 2017 at WBDC, and SF-RWR and SF-HBG mixtures in 2017 at AAFC SCRDC was because of low steer weight gain. Despite no greenfeed revenue, positive net returns were observed in 2017 at AAFC SCRDC site. This was because more steer grazing days and high steer weight gains were achieved. This suggests that beef producers must determine their potential costs, revenues and returns and choose species that will meet their production and financial goals. The fact that low or moderate stocking rate had an influence on ADG and animal unit gain (Jones and Sandland, 1974; Popp et al., 1997; Holechek et al., 1999), it is advisable for producers to adopt stocking rates that meet their production goals for profit. Producers also need to use steers for grazing.

The economic comparison in this study was done with the revenue coming from custom grazing stocker cattle. If the stockers been bought and sold, there are market forces that would come into play and likely affect revenue outcomes differently than a set custom grazing fee. These results suggest that beef producers must adopt placing value on forages for higher profit compared to compensation rates for custom grazing and animal grazing days. Net returns of forage valuation were greater for ALF-HBG and SF-HBG mixtures at WBDC and ALF-RWR mixture at AAFC SCRDC site. This suggests that a producer who adopts net returns from forage valuation must consider the adaptability of forage species at a specific soil zones for higher positive net returns. If a producer adopts compensation rate based on animal grazing days or animal weight gain, then the producer must consider light stocking rate for more animal grazing days and higher daily weight gain. In spite of all three valuations and soil-climatic variations, binary mixtures were suitable economically in Saskatchewan.

6.5 References

Alberta Agriculture and Forestry. 2018. Average farm input prices for Alberta. Accessed from: https://www.agric.gov.ab.ca/app21/farminputprices

Alberta Agriculture and Forestry. 2017. Multi-Year Economic, Productive and Financial Performance of Alberta Cow/Calf Operations. Available: http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/econ8479

Holechek, J.J., Gomez, H., Molinar, F. and Galt, D. 1999. Grazing studies: what we've learned. Rangelands 21(2): 12–16.

Jones, R. J. and Sandland, R. L. 1974. The relation between animal gain and stocking rate: derivation of the relation from the results of grazing trials. J. Agric. Sci. (Camb.).83: 335-342

Lang, K. 2006. From grain to grass – 6-year analysis. Western Beef Development Centre, Humboldt, Saskatchewan.

Lauriault L.M., Guldan, S.J. and Martin, C.A. 2003. Irrigated tall fescue-legume communities in the southern Rocky Mountains: years five to eight. Agron. J. 95:1497–1503.

Popp, J.D., McCaughey, W.P. and Cohen, R.D.H. 1997. Grazing system and stocking rate effects on the productivity, botanical composition and soil surface characteristics of alfalfa-grass pastures. Can. J. Anim. Sci. 77: 669–676

Saskatchewan Forage Council. 2011. An Economic Assessment of Feed Costs within the Cow/calf Sector.

Saskatchewan Forage Council. 2015. Market Report from Sept 2015. http://www.saskforage.ca/index.php/market-reports.html.

Saskatchewan Forage Council. 2016. Forage Market Price Discovery – September 2016. 29 pp. Available online: http://www.saskforage.ca/images/pdfs/Market_Reports/2016ForageMarket.pdf.

Saskatchewan Ministry of Agriculture. 2016. Farm Machinery Custom and Rental Rate Guide. 50 pp.

USDA. 2009. Agricultural Prices 2009 Summary. Pr 1-3(09). USDA National Agricultural Statistics Service, Washington, DC. http://usda.mannlib.cornell.edu/usda/nass/AgriPricSu//2000s/2009/AgriPricSu-08-05-2009.pdf (accessed 15 Nov. 2011).

Ward, C.I. 2009. The effect of perennial grass species on forage growth and quality, etiolated growth, animal performance and economics. MSc Thesis. University of Saskatchewan, Saskatoon, SK.

Western Beef Development Centre. 2015. Western Canadian cow-calf survey. http://westernbeef.org/pdfs/economics/WCCCS_Summary_Overall_Jun2015.pdf.

7 General Discussion and Conclusion

In an effort to find cost effective ways to increase profitability, many producers are looking for methods to maximize their net return on their livestock operation. The reliance of the livestock industry on perennial forages as a cost-effective and sustainable source of feed means that new forage varieties will continue to be developed and will need to be evaluated for their grazing potential in western Canada (Thompson, 2003).

The variations in soil and climatic condition of the two study sites had an effect on all parameters measured including biomass yield, botanical composition, nutritive value of clipped and hand plucked samples and grazing animal performance.

As well as providing stockpiled forage, most of the binary mixtures in the small plot study at AAFC SCRDC and AAFC Saskatoon provided enough biomass to meet the minimum requirement (2,000 kg ha^{-1}) for fall grazing (Alberta Agriculture and Forestry, 2008). However, GCM-RWR and WPC-RWR mixtures failed to meet the minimum biomass yield as a result of poor performance from GCM and WPC in mixture with Tom Russian wildrye. *Tom* Russian wildrye + legumes mixtures ranked highest in nutritive value while legumes + HBG mixtures ranked highest in biomass yield in both yrs and sites. All binary mixtures produced 15 to 22% greater yield in the July harvest compared to the September harvest date in 2017 at AAFC SCRDC and AAFC Saskatoon as a result of lower precipitation in 2017 compared to 2016.

The current study which was a mixed-row seeding had shown that legumes were more compatible with RWR than MBG or HBG at both sites. On the other hand, HBG was most aggressive to legumes followed by MBG + legumes mixtures. The aggressive growth nature of HBG out yielded most of the legumes in mixtures which in part affected yield and quality of the mixtures since legumes have higher crude protein, calcium and greater digestibility compared to grass species (Sleugh et al., 2000; Cox, 2013).

All tame binary mixtures met the nutrient requirement for beef cattle at cows in mid-gestation and lactation (NASEM, 2016). However, native binary mixtures performed well in yield and nutritive parameters, all failed in meeting the NASEM (2016), CP requirement of beef cattle except GCM-RWR mixture. Despite the warm and lower precipitation in 2017 compared to 2016, the native binary mixtures had lower ADF and NDF concentrations. The result suggests that native binary mixtures are more drought tolerant because lower fibre concentrations were observed in the 2017 compared to 2016, although CP concentration unchanged. The fact that all native binary mixtures were in the low-quality class of NASEM (2016), except GCM-RWR mixture and also most mixtures failed to meet the minimum yield of 2,000 kg ha^{-1} (Alberta Agriculture and Forestry, 2008), suggests that native binary mixtures are not good option for late summer and fall grazing.

In the grazing study conducted at WBDC and AAFC SCRDC sites, all binary mixtures examined in this study produced biomass yield greater than the minimum forage yield (2,000 kg ha^{-1}) (Alberta Agriculture and Forestry, 2008), for summer and fall grazing in western Canada. The well adaptation of HBG in the Aspen Parkland (Saskatchewan Forage Council, 2007), in mixtures with SF or ALF produced greater yield than SF-RWR and ALF-RWR mixtures at WBDC while biomass yield of binary mixtures at AAFC SCRDC were similar. Estimated biomass yield was an average 15% greater at WBDC compared to AAFC SCRDC. Composition of grass species was an average 26% greater at WBDC compared to AAFC SCRDC site. This suggests that grass species grow better in Black soil zone while legume species grow better in Brown soil zone which supports an earlier study (Hayne, 1980). Tom Russian wildrye in mixtures with SF and ALF were more compatible compared to HBG in mixtures with SF and ALF at both sites.

Tom Russian wildrye in mixtures with SF or ALF performed better in nutritive value compared to SF-HBG and ALF-HBG mixtures in both yrs at WBDC and 2017 at AAFC SCRDC site.

As cattle have the ability to graze selectively, nutrient quality of grazed herbage (hand plucked) was greater than that estimated by clipping forage from pasture at WBDC while similar at AAFC SCRDC site. All binary mixtures meet the NASEM (2016), CP and TDN beef cattle nutrient requirement for at least cows in gestation and lactation stage of production. Fibre concentrations of both clipped and plucked samples from binary mixtures were low quality (>35.0% ADF and 50.0% NDF) based on NASEM (2016). In conclusion all binary mixtures are good for late summer and fall month grazing for better animal performance with or without dietary supplement. Regardless of the grazing season (late summer to fall), all binary mixtures produced beef cattle with AGD and TBP comparable to similar pastures grazed in spring or summer at same study sites. This suggests that binary mixtures are good candidates for late summer and fall grazing in the Brown and Thin Black soil zones in Saskatchewan.

Higher seeding rates at WBDC resulted in higher establishment costs compared to AAFC SCRDC site. Revenue from greenfeed in 2016 at WBDC reduced cost to seed pasture mixture by 100 percent. This suggests that producers should seed an annual crop cover for revenue in 2016 to reduce costs of seeding perennial binary mixtures in 2016 since perennial pastures are not grazed in seeding (establishment) year. Net returns of forage valuation were the greatest compared to compensation rates for custom grazing and animal grazing days. These results suggest that beef producers must adopt placing value on forages for higher profit compared to compensation rates for custom grazing and animal grazing days. The conclusion from the current study is for two years (preliminary results) and additional results will be needed to validate this conclusion.

7.1 Future Research

This 2-yr study has provided an examination of the potential of a range of binary mixture stands for use in summer and fall months stockpiling systems. Five (AAFC Saskatoon) and six (AAFC SCRDC) tame legume and three (AAFC SCRDC) native legumes in binary mixtures with three cool-season grass species in a mixed row pattern as a small plot study. All experiments were conducted under field conditions. Most studies in the United State and Canada had focused on binary mixtures in mixed row pattern to determine yield and botanical composition. Limited data is available in western Canada pertaining to binary mixtures in an alternate or cross seeding row pattern. Future studies should investigate binary mixtures seeded in an alternate row or cross row pattern to compare biomass yield and composition of legumes in mixtures to mixed row seeding pattern. In addition, this study was conducted at one site each in the Dark Brown and Brown soil zones, so it is unknown whether our results can be extrapolated to other zones in the Canadian prairies. Similar experiments should be conducted in Black soil zones so to compare results from these other sites.

In the grazing study however, most studies had focused on grazing preference using esophageal fistula and clipping samples. Limited data is available on grazing preference via hand plucking and clipping samples. Future studies should investigate hand plucking at different grazing days; 0, 7, 14 and 21 d and compare to clipping samples in Brown, Black and Dark Brown soil zones in Saskatchewan. Most studies had also focused on addition of legumes to increase yield and quality in the Canadian prairies. Limited data is available comparing how incorporation of legumes to grass species improve carrying capacity. Future studies should investigate how addition of legumes to grass species improve carrying capacity compared to grass monoculture.

7.2 References

Alberta Agriculture and Forestry. 2008. Agronomic Management of Stockpiled Pastures. Agdex 420/56-4. Accessed from: https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex12422.

Cox, S.R. 2013. Forage yield and quality of binary grass-legume mixtures of tall fescue, orchardgrass, meadow brome, alfalfa, birdsfoot trefoil, and cicer milkvetch. MSc Thesis. Utah State University, Logan, Utah.

Haynes, R.J. 1980. Competitive aspects of the grass-legume association. Adv. Agron., 33: 227–261.

NASEM. 2016. National academics of Sciences, engineering, and medicine. Nutrient requirement of beef cattle. Eighth revised edition. Washington, DC.

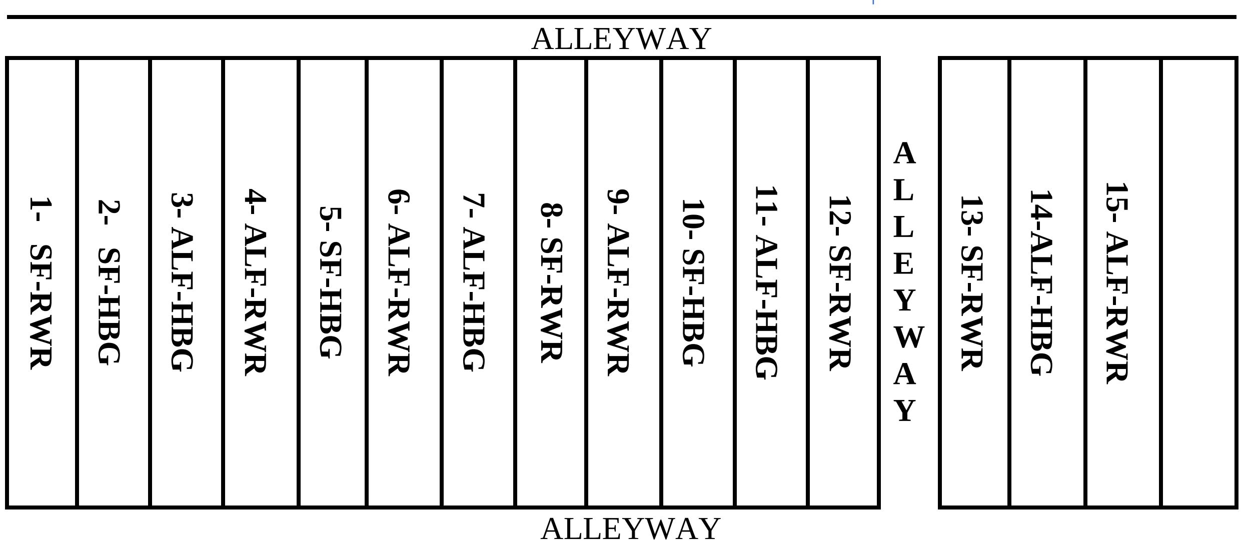
Sleugh, B., Moore, K.J., George, J.R. and Brummer, E.C. 2000. Binary legume–grass mixtures improve forage yield, quality, and seasonal distribution. Agron. J. 92: 24–29.

Thompson, L. 2003. Forage production and performance of beef yearling graziing hybrid bromegrass. MSc. Thesis. Dept. of Animal and Poultry Science. University of Saskatchewan, Saskatoon, SK.

Appendix

Figure A.1. Plot plan of pasture at AAFC SCRDC

12.9 hectare divided into16, 0.8 ha paddocks N

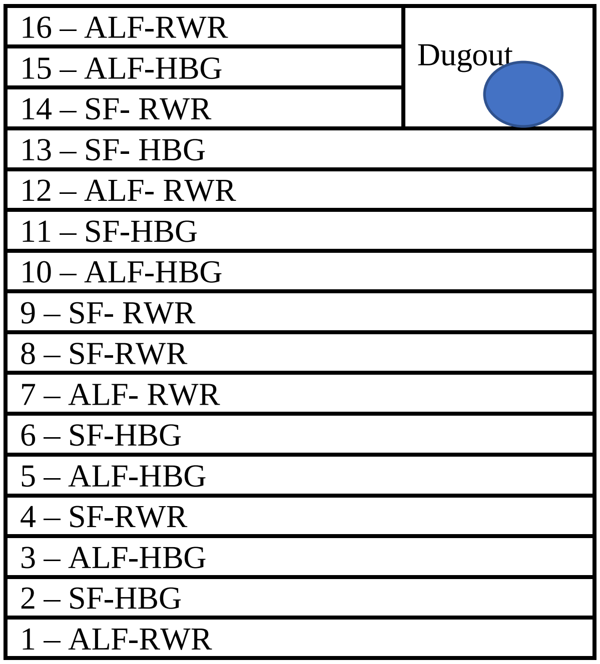


SF = AC Mountainview sainfoin
HBG = AC Success hybrid bromegrass
ALF = AC Yellowhead alfalfa
RWR = Tom Russian wildrye

Figure A.2. Plot plan of pasture at WBDC

10.7 hectare divided into 16, 0.7 ha paddocks

N



ALF = AC Yellowhead alfalfa
SF = AC Mountainview sainfoin
HBG = AC Success hybrid bromegrass
RWR = Tom Russian wildrye

Figure A.3. Plot Plan of Pasture at AAFC- Saskatoon

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18	R19	R20
Entry		14	13	15	1	2	3	16	18	17	6	5	4	12	10	11	7	8	9	
Plot	**G**	**401**	**402**	**403**	**404**	**405**	**406**	**407**	**408**	**409**	**410**	**411**	**412**	**413**	**414**	**415**	**416**	**417**	**418**	**G**
Entry		2	1	3	14	13	15	8	9	7	5	4	6	11	10	12	18	17	16	
Plot	**G**	**301**	**302**	**303**	**304**	**305**	**306**	**307**	**308**	**309**	**310**	**311**	**312**	**313**	**314**	**315**	**316**	**317**	**318**	**G**
Entry		7	8	9	15	14	13	16	17	18	3	1	2	5	4	6	10	11	12	
Plot	**G**	**201**	**202**	**203**	**204**	**205**	**206**	**207**	**208**	**209**	**210**	**211**	**212**	**213**	**214**	**215**	**216**	**217**	**218**	**G**
Entry		15	14	13	18	16	17	10	12	11	4	5	6	9	8	7	1	3	2	
Plot	**G**	**101**	**102**	**103**	**104**	**105**	**106**	**107**	**108**	**109**	**110**	**111**	**112**	**113**	**114**	**115**	**116**	**117**	**118**	**G**

G=Guard - Kirk (crested wheatgrass); 1 = AC Yellowhead alfalfa-Tom Russian wildrye; 2 = AC Yellowhead alfalfa-AC Success hybrid bromegrass; 3 = AC Yellowhead alfalfa-Admiral meadow bromegrass; 4 = Nova sainfoin-Tom Russian wildrye; 5 = Nova sainfoin-AC Success hybrid bromegrass; 6 = Nova sainfoin-Admiral meadow bromegrass; 7 = AC Mountainview sainfoin-Tom Russian wildrye; 8 = AC Mountainview sainfoin -AC Success hybrid bromegrass; 9 =AC Mountainview sainfoin-Admiral meadow bromegrass; 10 = Great Plains-Ecovar Canadian milkvetch-Tom Russian wildrye; 11 = Great Plains-Ecovar Canadian milkvetch -AC Success hybrid bromegrass; 12 = Great Plains-Ecovar Canadian milkvetch -Admiral meadow bromegrass; 13 = AC Veldt cicer milkvetch-Tom Russian wildrye; 14 = AC Veldt cicer milkvetch -AC Success hybrid bromegrass; 15 = AC Veldt cicer milkvetch -Admiral meadow bromegrass; 16 = Shoshone sainfoin-Tom Russian wildrye; 17 = Shoshone sainfoin-AC Success hybrid bromegrass; 18 = Shoshone sainfoin-Admiral meadow bromegrass

Figure A.4. **Plot Plan of Pasture at AAFC SCRDC**

July Harvest

Rep 1	Rep 2	Rep 3	Rep 4
1 MBG GCM	37 RWR DSF	73 HBG CMV	109 HBG DSF
2 RWR GCM	38 MBG DSF	74 MBG CMV	110 MBG DSF
3 HBG GCM	39 HBG DSF	75 BOZ CMV	111 BOZ DSF
4 BOZ GCM	40 BOZ DSF	76 RWR CMV	112 RWR DSF
5 BOZ CMV	41 HBG PPC	77 MBG PPC	113 MBG NSF
6 RWR CMV	42 MBG PPC	78 BOZ PPC	114 RWR NSF
7 MBG CMV	43 BOZ PPC	79 HBG PPC	115 HBG NSF
8 HBG CM	44 RW PPC	80 RW PPC	116 BOZ NSF
9 HBG PPC	45 MBG ALF	81 RWR ALF	117 MBG PPC
10 RWR PPC	46 RWR ALF	82 HBG ALF	118 HBG PPC
11 MBG PPC	47 HBG ALF	83 MBG ALF	119 RWR PPC
12 BOZ PPC	48 BOZ ALF	84 BOZ ALF	120 BOZ PPC

September harvest

Rep 1	Rep 2	Rep 3	Rep 4
1 RWR CMV	37 RWR DSF	73 RWR PPC	109 HBG SSF
2 HBG CMV	38 BOZ DSF	74 BOZ PPC	110 BOZ SSF
3 MBG CMV	39 HBG DSF	75 MBG PPC	111 MBG SSF
4 BOZ CMV	40 MBG DSF	76 HBG PPC	112 RWR SSF
5 RWR SSF	41 HBG ALF	77 HBG CMV	113 HBG ALF
6 BOZ SSF	42 MBG ALF	78 BOZ CMV	114 BOZ ALF
7 HBG SSF	43 RWR ALF	79 MBG CMV	115 MBG ALF
8 MBG SSF	44 BOZ ALF	80 RWR CMV	116 RWR ALF
9 RWR PPC	45 HBG ALF	81 RWR ALF	117 RWR NSF
10 MBG PPC	46 RWR ALF	82 MBG ALF	118 MBG NSF
11 BOZ PPC	47 MBG ALF	83 BOZ ALF	119 HBG NSF
12 HBG PPC	48 BOZ ALF	84 HBG ALF	120 BOZ NSF

121	122	123	124	125	126	127	128	129	130	131	132	133	134	135
RWR	**HBG**	**MBG**	**BOZ**	**RWR**	**BOZ**	**MBG**	**HBG**	**BOZ**	**HBG**	**MBG**	**RWR**	**BOZ**	**RWR**	**MBG**
CMV	**CMV**	**CMV**	**CMV**	**WPC**	**WPC**	**WPC**	**WPC**	**DSF**	**DSF**	**DSF**	**DSF**	**GCM**	**GCM**	**GCM**

85	86	87	88	89	90	91	92	93	94	95	96	97	98	99
BOZ	**HBG**	**MBG**	**RWR**	**RWR**	**BOZ**	**MBG**	**HBG**	**MBG**	**BOZ**	**RWR**	**HBG**	**HBG**	**RWR**	**BOZ**
NSF	**NSF**	**NSF**	**NSF**	**ALF**	**ALF**	**ALF**	**ALF**	**WPC**	**WPC**	**WPC**	**WPC**	**DSF**	**DSF**	**DSF**

49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
BOZ	**MBG**	**HBG**	**RWR**	**MBG**	**BOZ**	**RWR**	**HBG**	**BOZ**	**MBG**	**RWR**	**HBG**	**RWR**	**BOZ**	**MBG**
PPC	**PPC**	**PPC**	**PPC**	**CMV**	**CMV**	**CMV**	**CMV**	**GCM**	**GCM**	**GCM**	**GCM**	**WPC**	**WPC**	**WPC**

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
HBG	**BOZ**	**RWR**	**MBG**	**BOZ**	**HBG**	**RWR**	**MBG**	**RWR**	**BOZ**	**HBG**	**MBG**	**MBG**	**BOZ**	**RWR**
ALF	**ALF**	**ALF**	**ALF**	**GCM**	**GCM**	**GCM**	**GCM**	**DSF**	**DSF**	**DSF**	**DSF**	**WPC**	**WPC**	**WPC**

121	122	123	124	125	126	127	128	129	130	131	132	133	134	135
BOZ	**MBG**	**RWR**	**HBG**	**BOZ**	**RWR**	**MBG**	**HBG**	**RWR**	**MBG**	**BOZ**	**HBG**	**HBG**	**RWR**	**BOZ**
ALF	**ALF**	**ALF**	**ALF**	**CMV**	**CMV**	**CMV**	**CM**	**WPC**	**WPC**	**WPC**	**WPC**	**GCM**	**GCM**	**GCM**

85	86	87	88	89	90	91	92	93	94	95	96	97	98	99
RWR	**HBG**	**MBG**	**BOZ**	**MBG**	**RWR**	**BOZ**	**HBG**	**RWR**	**MBG**	**BOZ**	**HBG**	**MBG**	**HBG**	**BOZ**
SSF	**SSF**	**SSF**	**SSF**	**GCM**	**GCM**	**GCM**	**GC**	**WPC**	**WPC**	**WPC**	**WPC**	**NSF**	**NSF**	**NSF**

49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
RWR	**HBG**	**BOZ**	**MBG**	**HBG**	**MBG**	**BOZ**	**RW**	**MBG**	**BOZ**	**RWR**	**HBG**	**BOZ**	**HBG**	**MBG**
SSF	**SSF**	**SSF**	**SSF**	**WPC**	**WPC**	**WPC**	**WP**	**NSF**	**NSF**	**NSF**	**NSF**	**GCM**	**GCM**	**GCM**

13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
BOZ	**HBG**	**MBG**	**RWR**	**BOZ**	**RWR**	**MBG**	**HBG**	**BOZ**	**RWR**	**MBG**	**HBG**	**BOZ**	**RWR**	**MBG**
DSF	**DSF**	**DSF**	**DSF**	**ALF**	**ALF**	**ALF**	**ALF**	**NSF**	**NSF**	**NSF**	**NSF**	**ALF**	**ALF**	**ALF**

28 **HBG** **ALF**	29 **HBG** **SSF**	30 **BOZ** **SSF**	31 **RWR** **SSF**	32 **MBG** **SSF**	33 **MBG** **WPC**	34 **HBG** **WPC**	35 **RWR** **WPC**	36 **BOZ** **WPC**
64 **RWR** **GCM**	65 **HBG** **CMV**	66 **RWR** **CMV**	67 **BOZ** **CMV**	68 **MBG** **CMV**	69 **MBG** **ALF**	70 **HBG** **ALF**	71 **BOZ** **ALF**	72 **RWR** **ALF**
100 **RWR** **NSF**	101 **HBG** **ALF**	102 **RWR** **ALF**	103 **BOZ** **ALF**	104 **MBG** **ALF**	105 **HBG** **DSF**	106 **BOZ** **DSF**	107 **MBG** **DSF**	108 **RWR** **DSF**
136 **MBG** **GCM**	137 **MBG** **SSF**	138 **HBG** **SSF**	139 **BOZ** **SSF**	140 **RWR** **SSF**	141 **BOZ** **ALF**	142 **RWR** **ALF**	143 **HBG** **ALF**	144 **MBG** **ALF**
28 **HBG** **WPC**	29 **RWR** **NSF**	30 **HBG** **NSF**	31 **BOZ** **NSF**	32 **MBG** **NSF**	33 **BOZ** **ALF**	34 **HBG** **ALF**	35 **MBG** **ALF**	36 **RWR** **ALF**
64 **HBG** **WPC**	65 **RWR** **SSF**	66 **HBG** **SSF**	67 **BOZ** **SSF**	68 **MBG** **SSF**	69 **MBG** **NSF**	70 **RWR** **NSF**	71 **BOZ** **NSF**	72 **HBG** **NSF**
100 **MBG** **DSF**	101 **MBG** **SSF**	102 **RWR** **SSF**	103 **HBG** **SSF**	104 **BOZ** **SSF**	105 **RWR** **GCM**	106 **MBG** **GCM**	107 **HBG** **GCM**	108 **BOZ** **GCM**
136 **HBG** **GCM**	137 **HBG** **ALF**	138 **RWR** **ALF**	139 **MBG** **ALF**	140 **BOZ** **ALF**	141 **BOZ** **PPC**	142 **HBG** **PPC**	143 **MBG** **PPC**	144 **RWR** **PPC**

ALF= AC Yellowhead alfalfa; MSF = AC Mountainview sainfoin; NSF = Nova sainfoin; GCM = Great Plains-Ecovar Canadian milkvetch; CMV= AC Veldt cicer milkvetch; SSF = Shoshone sainfoin; DEL = Delaney sainfoin; PPC = AC Lamour purple prairie clover; WPC = AC Antelope white prairie clover; RWR = Tom Russian wildrye; HBG =AC Success hybrid bromegrass; MBG =Admiral meadow bromegrass; BOZ = Bozoisky II Russian wildrye.

Table A.1. Soil Nitrogen (NO_3-N), Phosphorus (PO_4-P), Potassium (K_2O-K) and Sulfur (SO_4-S) Levels for Binary Pasture Mixtures at Different Soil Depth at WBDC and AAFC Saskatoon (2015, 2016, 2017).

Site-year	Treatments	Depth	NO_3-N	P_2O_5-P	K_2O	SO_4-S
		---cm----	----------------------kg ha^{-1}---------------------------			
AAFC Saskatoon						
2015		0-30	6	76	1143	11
WBDC						
2105		0-30	179	134	1278	108
2016	ALF-RWR	0-15	7	24	474	21
	ALF-HBG	0-15	8	26	462	20
	SF-RWR	0-15	10	45	558	22
	SF-HBG	0-15	9	35	563	26
2017	ALF-RWR	0-15	16	25	587	473
	ALF-HBG	0-15	14	52	558	21
	SF-RWR	0-15	15	42	591	20
	SF-HBG	0-15	16	51	642	53

Table A.2. Soil Nitrogen (NO_3-N), Phosphorus (PO_4-P), Potassium (K_2O-K) and Sulfur (SO_4-S) Levels for Binary Pasture Mixtures at Different Soil Depth at AAFC SCRDC (2015, 2016, 2017)

Site- year	treatment	depth	NO_3-N	P_2O_5-P
		cm	------------- kg ha^{-1}------------------------------	
AAFC SCRDC (Grazing study plot)				
2015	ALF-RWR	0-15	27	22
		15-30	25	10
		30-60	52	15
		60-90	42	18
	ALF-HBG	0-15	26	18
		15-30	26	13
		30-60	52	15
		60-90	41	14
	SF-RWR	0-15	36	36
		15-30	30	16
		30-60	60	20
		60-90	43	19
	SF-HBG	0-15	31	22
		15-30	27	9
		30-60	51	12
		60-90	41	12

Table A.2. Soil Nitrogen (NO_3-N), Phosphorus (PO_4-P), Potassium (K_2O-K) and Sulfur (SO_4-S) Levels for Binary Pasture Mixtures at Different Soil Depth at AAFC SCRDC (2015, 2016, 2017) Continued

Site-year	Treatment	Depth	NO_3-N	P_2O-P
AAFC SCRDC (Grazing plot)		-cm	------------kg ha^{-1}-------------------	
2016	ALF-RWR	0-15	11	21
		15-30	18	7
		30-60	26	13
		60-90	19	18
	ALF-HBG	0-15	10	20
		15-30	19	9
		30-60	27	14
		60-90	12	13
	SF-RWR	0-15	15	32
		15-30	22	7
		30-60	32	10
		60-90	18	10
	SF-HBG	0-15	8	19
		15-30	8	8
		30-60	18	10
		60-90	15	10
AAFC SCRDC (Small plot study)				
2015		0-15	34	36
		15-30	21	33
		30-60	15	6
		60-90	9	7